National Audubon Society Pocket Guide

Planets and Their Moons

NATIONAL AUDUBON SOCIETY POCKET GUIDE

NATIONAL AUDUBON SOCIETY

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PLANETS AND THEIR MOONS

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How to Use This Guide

The planets of our solar system are our closest celestial neighbors, locked in orbit around our central star, the Sun. For millennia human beings have followed the planets in our skies, attaching myths to them, making astronomical predictions based on their positions, searching for life on them, and studying them to determine the origin of our own planet and to learn why Earth alone has given rise to life. This book provides detailed photographs and descriptions of the planets and other solar system bodies, as well as information on how to locate and observe them in the sky.

Coverage

This guide covers the nine planets—Mercury, Venus, Earth, Mars, Jupiter, Saturn, Uranus, Neptune, and Pluto—and their satellites (or moons, as they are commonly called), as well as other bodies that share our solar system: asteroids and comets.

Organization

This easy-to-use pocket guide is divided into three parts: introductory essays, illustrated descriptions of the planets and their moons, and appendices.

Introduction

The introductory essay "The Solar System" explains how our Sun and its attendant planets and smaller objects came into being several billion years ago and evolved into

the celestial bodies we know today. "Planetary Motion" discusses the actual movements of the planets around the Sun as well as the movements we perceive in relation to our own moving planet. A discussion on the changing positions of the planets relative to Earth and the Sun, accompanied by explanatory diagrams, provides essential information for observing the planets from Earth and describes the best times to see the different planets.

The Planets and Their Moons

This section includes 80 photographs of the planets, their moons, and smaller solar system bodies (comets and asteroids). The wide variety of images includes Earth-based photographs, images compiled from radar and other satellite data, photographs snapped by space shuttle astronauts, and images supplied by numerous spacecraft, including the newly repaired Hubble Space Telescope. For all of the planets for which such photographs are available we have presented global images as well as close-ups of details. Opposite each color plate is a detailed text account that identifies and describes the object or feature pictured. The section begins with two composite photographs that compare the different types of planets and moons of our solar system. The planets and their attendant moons are

covered in the order of their distance from the Sun. The section ends with comets, including comet Shoemaker-Levy 9, which smashed into Jupiter in 1994. On the first text page for each planet and moon is a table listing such data as the planet's (or moon's) size and its distance from the Sun (or parent planet). For quick reference in identifying the subject featured, each text description is accompanied by a black-and-white illustration. A global drawing of each planet accompanies all the pages covering that planet, its features, and its moons.

Appendices The appendices, which follow the color-plate section, provide information on finding the planets in the sky. A brief essay, "Observing the Planets," offers tips on locating the planets as they move across the celestial sphere. The zodiac chart and the Planetary Longitudes table provide information for plotting the locations of the planets that are most accessible to the amateur observer (Mercury, Venus, Mars, Jupiter, Saturn) on specific dates from 1995 through 2000. Planet Positions lists the dates when the planets visible to the naked eye are brightest and nearest to Earth. The index lists all the objects covered in the book.

The Solar System

Our Sun is one of several hundred billion stars in the Milky Way galaxy, a flat, spiral-shaped disk of stars 100,000 light-years across. The Sun is at the center of our solar system. Revolving around it are the nine planets—Mercury, Venus, Earth, Mars, Jupiter, Saturn, Uranus, Neptune, and Pluto (to remember their order, memorize the line "*M*y *V*ery *E*ducated *M*other *J*ust *S*erved *U*s *N*ine *P*ickles"); their satellites, including our Moon; a large number of minor planets (asteroids), most of which occur in an orbital band between the orbits of Mars and Jupiter known as the asteroid belt; and innumerable meteoroids and comets.

Formation

Scientists have developed theories about the formation of our solar system by observing its present-day structure and motions, which are artifacts of its origin. The formation of our solar system is thought to have been set into motion about 4.6 billion years ago, possibly when a nearby supernova (an explosion that signals the death of a very massive star) caused a massive cloud, or nebula, of gas and dust to contract. As the cloud contracted it began to rotate, heating up in the process and flattening into a disk. This cloud, now thick with dust, formed a giant whirlpool. Much of the material gravitated to the center

and gradually came to form the proto-sun. Smaller whirlpools and eddies collected materials that began to stick together, forming secondary concentrations of gases and dust that eventually built up to globules so massive that gravity within them began to squeeze the material inward, warming it. These proto-planets moved in roughly circular paths around the proto-sun. When the proto-sun, still contracting, became hot enough for nuclear fusion to occur, turbulence, angular momentum factors, and solar flare-ups conspired to sweep the solar system clean of most of the remaining gas. Left behind were the proto-planets and much solid debris. The solar heat baked the inner planets into small, hard, dense spheres. Those in outer, cooler regions retained their gases and became the gas giants we know today.

Over the next half-billion years or so, much of the stellar detritus collided with the proto-planets, adding to their masses. (On such bodies as Mercury, the Moon, and a number of other planetary satellites, which have no eroding atmosphere or plate tectonics to efface the impacts, craters from these colossal hits are still in evidence.) Chunks of debris were pulled into the

gravitational fields of some of the proto-planets, forming satellite systems. One collision, perhaps the largest, was between two planets, leaving the smaller engulfed by the larger, our Earth. Some of the material blasted out by this ferocious collision ended up in orbit in a clumpy ring, which relatively quickly formed our Moon.

A giant leap outward from Mars, with an orbital size more than three times larger, lay the largest secondary concentration of gases and dust, Jupiter. Far enough away from the Sun to escape the intense heat and massive enough for its gravity to hold onto its own lightweight elements, it was squeezing inward and glowing from the heat thus generated. Today Jupiter remains the largest and most massive planet of the solar system, more similar to a star than an Earth-like planet. The other gas giant planets—Saturn, Uranus, and Neptune—underwent similar processes. The very materials that were vaporized by the Sun's heat in the inner solar system froze in these outer portions. Of all these materials, none was more plentiful than the molecule made with hydrogen and oxygen—water.

The Planets Today

Eight of the nine planets in our solar system are classified as either terrestrial or jovian. The terrestrial (Earth-like)

planets are the ones closest to the Sun: Mercury, Venus, Earth, and Mars. They are characterized by their solidity, low mass, great density, and small size. They are basically metallic balls encased in rock, with either no atmosphere or a rather thin one. The jovian planets, or gas giants—Jupiter, Saturn, Uranus, and Neptune—lie beyond the asteroid belt (see below). Characterized by greater mass, lower density, and larger size, they have thick atmospheres composed mostly of hydrogen and helium. Pluto, only two-thirds the size of our Moon (itself one-quarter the size of Earth) and weighing far less, is singular among the planets. It is solid, like the terrestrial planets, but wasn't heat-tempered as they were. It is located in the realm of the gas giants, but it is neither gaseous nor giant. With recent findings about the compositions of comets, the icy satellites, and Pluto, astronomers are beginning to suspect that it may be an icy satellite or a very large comet rather than a puny planet.

Satellites

Only two of the terrestrial planets—Mars and Earth—have satellites (or moons, as they are commonly known). The jovian planets have extensive systems of satellites orbiting them. Jupiter and Saturn have several moons

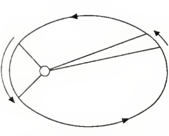
that are large enough to be seen in amateur telescopes, displaying a continually changing pattern as they orbit their parent planets. Some of the planetary satellites probably formed around their parent planet in a manner similar to the way the planets formed around the Sun. Others appear to be captured asteroids, such as Mars's small, lumpy moons, Phobos and Deimos. Our Moon probably formed when a fairly large body collided with Earth, sending a shower of debris into orbit that eventually clung together forming the Moon. The moons of our solar system range from tiny lumps of rock and ice to planet-size objects with atmospheres to mid-size moons exploding with volcanic activity. Internal heating and activity in a satellite are dependent on several factors, including the body's size and its distance from the gravitational fields of its parent planet and its sibling moons.

Comets and Asteroids

The many smaller bodies in our solar system are thought to be "leftover" material that failed to coalesce during the formation of the planets. Among the leftover debris were small chunks made of water ice, rocks, dust, and frozen gases such as methane and nitrogen. These chunks, typically a few miles in diameter, were flung out by the

gravities of the two outer giants, Uranus and Neptune, into regions called the Oort cloud and the Kuiper belt. There these pieces of leftover debris float in cold storage. Occasionally one becomes deflected by changing interstellar gravities and falls toward the Sun to the realm of the terrestrial planets. We observe it as a comet, boiling apart, with gases and dust streaming out. There were also left over from the solar system's formation chunks of rock and metals that could take the heat of the Sun. Most of these had collided and merged with the forming protoplanets or were pulled into their gravitational fields as satellites, but in the gap between Mars and Jupiter, the powerful gravity of the latter prevented those processes from occurring. Today these form the asteroid belt. About 5,000 asteroids—or minor planets—have been cataloged, and several hundred new ones are found every year. There are probably billions, only a few dozen of which are larger than 100 km (60 miles) across. Most are irregularly shaped, with chemical compositions ranging from metallic to stony to organic (though nonbiological) compounds of carbon, water, and other volatile materials.

Planetary Motion



Kepler's First and Second Laws

Planets in their orbits around the Sun and satellites in their orbits around the planets obey the laws of physics, in particular the *law of gravitation.* This law states that the force attracting two objects is proportional to the product of their masses and inversely proportional to the square of their distance from one another. Isaac Newton formulated this and other laws of physics in the mid-1600s, confirming three rules stated in the early 1600s by the German mathematician Johannes Kepler to describe the movements of the planets. *Kepler's first law* states that the shape of a planetary orbit is an ellipse, with the Sun at the focus. *Kepler's second law* states that a line connecting the Sun and a planet sweeps over equal areas in equal intervals of time, as illustrated at left (the areas delineated are equal). This means that a planet moves faster along its orbit when it is close to the Sun and more slowly when it is farther away. *Kepler's third law* states that the square of a planet's sidereal period (the time it takes to orbit the Sun once) is proportional to the cube of the planet's average distance from the Sun. This equation has enabled astronomers to calculate the planets' distances from the Sun. In satellite orbits the parent planet replaces the Sun as the focus of the orbit.

The planets all orbit the Sun in the same direction. The planets closer to the Sun move faster in their orbits than do the outer planets. It is this continual ballet of the planets, some speeding along, others meandering, that gives rise to the changing positions of the planets in our skies. (The word planet, meaning "wanderer," was given to these bodies because they seem to roam the heavens.) As we view a planet in the sky, it usually seems to move in an easterly direction against the background of stars. This rather slow movement can best be gauged by observing the planet's position on consecutive nights. Since we view the solar system from a moving platform, Earth, we perceive not just the movements of the other planets but, indirectly, our own movement as well.

Planetary Phenomena

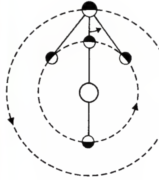
The changing positions of the planets relative to the position of Earth are referred to as planetary phenomena. These relative positions affect at what time of night (or day) the other planets appear in our skies.

The angle between the Sun and a planet as viewed from Earth is called the planet's *elongation*. When a planet is at eastern elongation, that is, east of the Sun as seen from Earth, it will appear in the evening sky after sunset. Such

planets are popularly called "evening stars." When a planet has a westerly elongation, it rises during the night before the Sun and is in the sky at dawn. Such planets are commonly called "morning stars." Periodically, when one of the inner (or "inferior") planets is passing Earth, or when Earth is passing one of the outer (or "superior") planets, that planet will seem to stop its eastward motion through the sky and begin to move westward against the starry background. This apparent change of direction is called *retrograde motion*. It is similar to the illusion produced when you pass a car on the highway, and the other car appears to be traveling backward relative to the faster motion of your vehicle.

Inferior Planets

The planets closer to the Sun than Earth—Mercury and Venus—are known as the inferior planets. Because they are closer to the Sun relative to Earth, they always appear near the Sun from our viewpoint, Mercury usually nearer than Venus. The diagram on the following page illustrates the four most significant positions of the inferior planets relative to Earth. The Sun is at the center of the drawing, Earth is in the outer orbit, and Venus or Mercury is represented in the four positions in the inner orbit.



Inferior Planet Positions

Inferior conjunction occurs when the inferior planet is between Earth and the Sun and, lost in the Sun's glare, is invisible to us. At *superior conjunction* the planet, again in a straight line with Earth and the Sun, is on the other side of the Sun from us and as far from Earth as it ever gets. We can't see the planet at superior conjunction either. At the conjunctions the planets are, for the most part, above the horizon during the daytime.

An inferior planet is at *greatest eastern elongation* when it reaches that point in its orbit at which it is as far east of the Sun as it can be from our point of view. *Greatest western elongation* occurs when the planet reaches its most westerly point in relation to the Sun as seen from Earth. The angle of greatest elongation—measured from the Earth-Sun line to the planet, as seen in the drawing—is a maximum of 27° for Mercury, 48° for Venus. As the inferior planets are as far from the Sun as they get (from our point of view) at the greatest elongations, and least obscured by the Sun's light, these are the best times to view them.

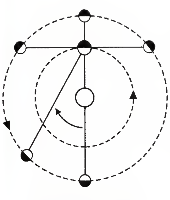
As the inferior planets move about the Sun they show phases—changes in apparent shape—and also change greatly in apparent size. The planets' phases are similar

to those of our Moon. They are at "new" phase at inferior conjunction, after which they grow from very thin crescents to half-circles at greatest western elongation. They are at full phase at superior conjunction, but they are hidden behind the Sun. The inferior planets are again half-illuminated at greatest eastern elongation, then become diminishing crescents until they return to the new phase. When they are on the same side of the Sun as Earth—from greatest eastern elongation through new to greatest western elongation—the inferior planets are at their largest. As they round the other side they decrease in size.

Superior Planets

The superior planets, those whose orbits are farther from the Sun than that of Earth—Mars, Jupiter, Saturn, Uranus, Neptune, and Pluto—can have maximum elongations of 180°. Their relative positions, illustrated on the next page, are described slightly differently than those of the inferior planets. The Sun is at the center of the drawing, Earth is in the inner orbit, and the superior planets are represented in the outer orbit in five positions.

When a superior planet is on the far side of the Sun—and as far from Earth as possible—it is said to be at



Superior Planet Positions

conjunction. Its elongation angle, measured from the Earth-Sun line to the planet, as illustrated, is 0° because it is in a straight line with Earth and the Sun. At *opposition* a planet is "opposite" the Sun, at a 180° angle, with Earth lying between it and the Sun. Opposition is the best time to view a superior planet: It is at its closest point to Earth, is fully illuminated, and is in the sky all night. When a superior planet's elongation angle is 90° in relation to the Sun as viewed from Earth, it is said to be at quadrature. At *eastern quadrature* (i.e., east of the Sun as seen from Earth) a planet appears in our evening skies; at *western quadrature* it is in our morning skies. The superior planets do not show phases as the inferior planets do. They always appear full or nearly so.

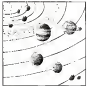
Sidereal and Synodic Periods

The period of time it takes a planet to complete a full cycle of its relative positions in our sky is called its *synodic period.* For a superior planet, the synodic period is the time it takes to travel from opposition to western quadrature, conjunction, eastern quadrature, and back to opposition. An inferior planet's synodic period measures the interval from inferior conjunction to greatest western

elongation, superior conjunction, greatest eastern elongation, and back to inferior conjunction. The synodic periods of planetary satellites are calculated relative to their parent planets, not to Earth. Our Moon's synodic period is the interval between successive new moons.

A planet's *sidereal period* is the time it takes to complete one revolution about the Sun. It is the measure of the planet's actual movement around its full orbit, or its "year." The sidereal period for Saturn is 29.5 Earth years, while its synodic period is just a little more than one Earth year. While Saturn is meandering around the Sun on its three-decade journey, Earth is literally whizzing past it, aligning with it in all four basic positions every 378 days.

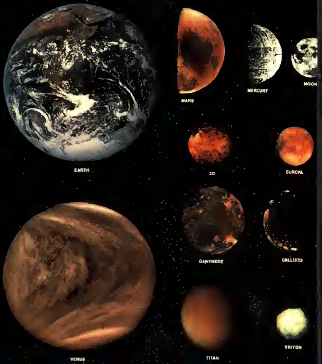
THE PLANETS AND THEIR MOONS



The Solar System

Comparison of terrestrial planets and larger satellites

When the solar system formed out of a huge, rotating disk of gas and dust around the central proto-sun 4.55 billion years ago, the ultimate composition of each planet and satellite depended in large part on its distance from the proto-sun. Those clumps of material that became the inner planets were baked hard by the proto-sun's heat, becoming solid masses of rock and metal, which can withstand heat without vaporizing into space. These planets are relatively dense, with metallic cores and rocky mantles and crusts, and have exhibited large-scale basaltic volcanism on the surface at some time. Farther out, in cooler regions, lighter-weight volatile materials built up and solidified, forming less dense gaseous planets orbited by satellites with rocky cores and icy mantles and crusts. This montage shows, to the same scale, the inner, rocky, terrestrial planets—Mercury, Venus, Earth, and Mars—as well as our Moon, and the larger satellites of the outer planets: Jupiter's Galilean satellites Io, Europa, Ganymede, and Callisto; Saturn's moon Titan; and Neptune's moon Triton.


EARTH
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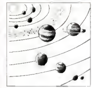
CALLISTO
VENUS
TITAN
TRITON



The Solar System
Comparison of jovian planets and Earth

The jovian or Jupiter-like planets, also called gas giants, are strikingly larger than Earth, the largest of the terrestrial-type planets. Jupiter's diameter is 11.2 times that of Earth, Saturn's is 9.5 times Earth's, while Uranus and Neptune are close to 4 times the diameter of our world (4.1 and 4.0 times, respectively). Jupiter, with a mass 318 times that of Earth, is more massive than all the other planets combined. Jovian planets are found in the outer, colder regions of the solar system. They exhibit no clear-cut solid surfaces (their composition gets steadily denser toward the core), and their gaseous composition is similar to that of stars, including our Sun—mostly hydrogen and helium. They display intense magnetic fields, low density (about that of water), large satellite families, and ring systems. Fast rotation and an internal heat source give their multi-layered cloud decks a banded appearance, particularly vivid in Jupiter and Saturn. Their atmospheres also contain small percentages of methane and ammonia.


EARTH

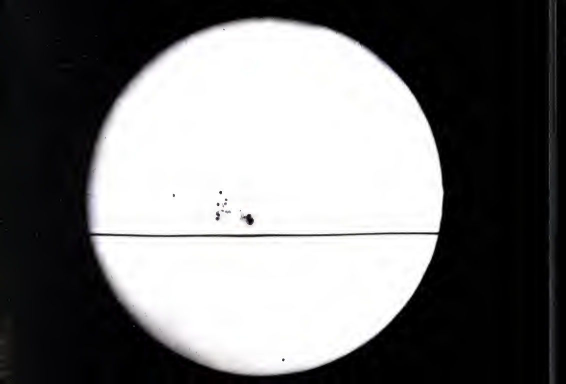
Mercury Data
Distance from Sun: 57.91 million km (35.99 million miles)
Diameter: 4,878 km (3,031 miles)
Mass: 0.0553 × Earth's mass
Density: 5.43 g/cm^3
Gravity: 0.378 × Earth's gravity
Rotation: 58.65 days
Axial Tilt: 0°
Sidereal Period: 87.97 days
Synodic Period: 115.88 days
Satellites: none

Mercury
Earth-based photograph

The innermost planet in our solar system, Mercury, named for the messenger of the gods, moves the most swiftly about the Sun. It is a terrestrial-type planet and the second-smallest planet of the solar system (after Pluto), in both size and mass. With virtually no atmosphere to insulate the planet, the surface facing the Sun reaches temperatures of about 400°C (well over 700°F), while the side away from the Sun drops to −170°C (−274°F). Mercury rotates on its axis very slowly, making a complete rotation in about 59 Earth days, while its year lasts about 88 Earth days. Mercury's orbit is quite eccentric, and its speed in orbit varies greatly. Because of this orbital eccentricity, Mercury's greatest elongation (apparent distance) from the Sun varies from about 16° to about 27°. This means that the planet never rises or sets very far from the Sun and is therefore visible during twilight (morning or evening). No surface detail of tiny Mercury is visible from Earth, as this humble view of the planet attests.

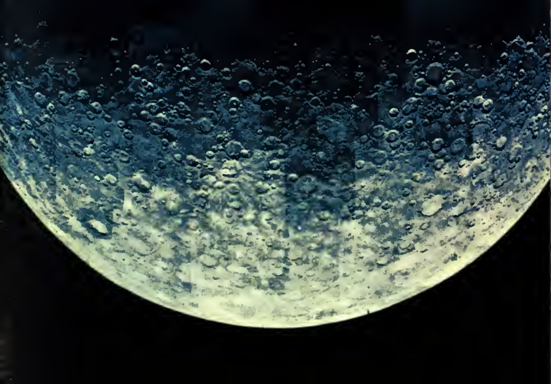
Mercury: Transit of the Sun
Earth-based photograph

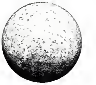
Mercury infrequently crosses in front of the disk of the Sun from our point of view, an occurrence called a transit. This photograph shows Mercury, the dot near the bottom, in the transit of November 14, 1907. (The origin of the horizontal dark line is not known. The large blotches are sunspots.) Mercury transits occur about 13 times per century. Were the solar system perfectly flat, every time Mercury reached inferior conjunction, that is, came between Earth and the Sun—about three times a year—a transit would occur. But because Mercury's orbit is tilted by 7° to Earth's orbit, the planet is usually above or below the Earth-Sun line at inferior conjunction. The next transits of Mercury will occur on November 14, 1999, and May 7, 2003. Venus also transits the Sun, about twice every 100 years; its next transits will occur on June 8, 2004, and June 6, 2012. To watch a transit safely, project the Sun onto a surface and watch the projected image. *Never look directly at the Sun to see this event.* You can make a simple projecting device using a shoe box with a small hole in one end and a piece of white paper at the other end.



Mercury: Quarter Phase
Mariner 10 *mosaic image*

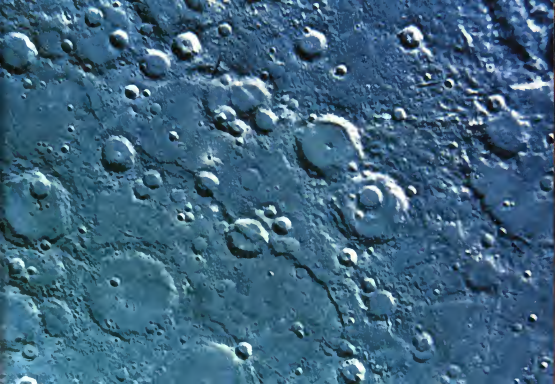
Swift Mercury, shown here at quarter phase, has a 116-day synodic period (the time it takes to complete a cycle of conjunctions and elongations in our skies). When Mercury is on the same side of the Sun as Earth, it is at its largest in our sky. At inferior conjunction, when it is directly between Earth and the Sun, it is closest to Earth—but rendered invisible by the Sun's light. As Mercury continues along its orbit it appears as a crescent (visible in telescopes), still relatively close to Earth and large in our sky. At its greatest western elongation (when it is as far west of the Sun as it can be from our point of view) it is at quarter phase and rises in the east as a morning star for about a week. At greatest eastern elongation it appears as an evening star, setting just after the Sun, again for about a week. At superior conjunction Mercury is as far from Earth as it gets and is invisible again as it disappears on the far side of the Sun. If we could see it then it would appear "full," but it would also be quite small. As a morning and evening star Mercury is one of the brightest objects in the sky.





Mercury: Discovery Scarp
Mariner 10 *image*

Mercury's surface, seen close up by the *Mariner 10* space probe in 1974–75, resembles that of the Moon. It is heavily cratered by meteorite impact and has several vast lava seas and mountainous regions. This image shows another type of feature, a long-running, smoothly curved cliff called a scarp, extending diagonally across the center of the image. This scarp was named Discovery after one of Captain James Cook's ships. Scarps are related to rift valleys, which appear commonly on other terrestrial bodies (Kenya's Great Rift Valley, Mars's Valles Marinaris, and the Moon's Alpine Valley, for example). Rift valleys form from tensional forces tearing apart the crust, while scarps form from compressional forces that occur when crusts squeeze together. Scarps can be thought of as large surface wrinkles and are evidence that as Mercury cooled it contracted, after its surface had solidified and been cratered. (Note that the scarp runs through the craters.) Mercury's craters are eroded in appearance.



Mercury: Caloris Basin
Mariner 10 *image*

One of the largest impact sites in the solar system, Caloris Basin was imaged by *Mariner 10* at the end of its first flyby of Mercury in March 1973. It is shown here (most of it was in darkness) at the bottom half of the photo as a series of concentric arcs. These arcs, seen throughout the solar system, are rims formed by the very largest impacts. Inside the ring of mountain ranges, toward the center, the basin has been filled in by lava flows. The Mare Orientale basin on the Moon and the Valhalla Basin on Callisto are other examples of this type of crater. The Valhalla feature has more concentric rims that are more closely spaced, presumably due to the surface's icy nature. (Ice, which has less tensile strength than rock, "scrunches" more under compressional strain.) One interesting aspect of Caloris Basin, not shown here, is on the opposite side of the planet, where *Mariner 10* revealed a heavily cratered, fractured terrain with apparent stretch marks. This topography, referred to as chaotic terrain, apparently resulted from a focusing of shock waves from the impact that formed the basin.

Venus Data
Distance from Sun: 108.2 million km (67.2 million miles)
Diameter: 12,102 km (7,520 miles)
Mass: 0.8149 × Earth's mass
Density: 5.25 g/cm^3
Gravity: 0.905 × Earth's gravity
Rotation: 243.0 days (retrograde)
Axial Tilt: 178°
Sidereal Period: 224.7 days
Synodic Period: 583.92 days
Satellites: none

Venus
Earth-based photograph

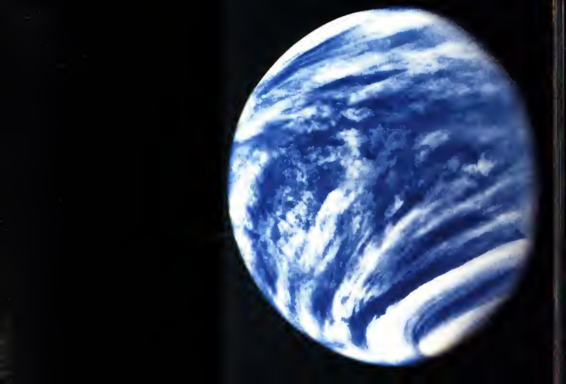
This photograph shows a magnified view of the planet Venus near the crescent Moon. These two bright objects are often partners in the sky after sunset or before sunrise. Venus is the brightest planet and the third-brightest celestial object (after the Sun and Moon), appearing brilliant white at its greatest magnitude of −4.6. In some early writings Venus was referred to as two separate entities, the Morning Star and the Evening Star. The planet is always within 48° of the Sun. When it is east of the Sun, it appears to trail the Sun as Earth turns, remaining in the sky after sunset. When to the Sun's west, Venus leads the Sun, rising in the morning before it. The second planet from the Sun, Venus is of the terrestrial type, with a thick, obscuring atmosphere 90 times denser than Earth's. It is one of the few bodies in the solar system to rotate east to west. Venus also has the slowest rotation of any planet, taking about 243 Earth days to complete one turn. Its "year," 225 Earth days, is shorter than its "day." Venus comes closer to Earth than any other planet, within about 15 million km (25 million miles).

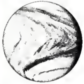
Venus: Phases
Earth-based photographs

Venus and all other planets, moons, and asteroids shine by the reflected light of the Sun. Venus is the third-brightest object in our sky, after the Sun and Moon, because of its highly reflective clouds and its proximity to both Earth and the Sun. The side of Venus facing the Sun is illuminated, while the opposite side is dark. As Venus orbits the Sun, the Earth-Venus-Sun angle changes, and we see Venus going through phases. When Venus is directly between Earth and the Sun, at inferior conjunction, the unlit side faces Earth. At this time a thin circle of light, refracted by the atmosphere, is visible surrounding the planet. As more of the lit side of Venus comes into view, we see Venus going through crescent, quarter (greatest western elongation), and gibbous phases. As Venus gets farther away from Earth, it appears to shrink. Its distance from Earth ranges from about 15 to 60 million km (25 to 100 million miles), so the size differential is substantial. This series of photographs illustrates the planet's changing shape and size as it moves around the Sun.

Venus: Atmosphere
Mariner 10 *ultraviolet image*

The surface of Venus is hidden from view behind a thick layer of obscuring clouds. To the naked eye Venus appears as a bland, almost featureless white sphere with a slightly yellowish hue. Viewed in ultraviolet light, as in this image taken by *Mariner 10* in 1974, the structure of the upper atmosphere becomes clear. The blue is a false-color representation of the UV albedo (reflectance) of Venus. Because the solid planet beneath spins very slowly, taking 243 days to complete one full rotation, the atmosphere moves in a global, worldwide weather pattern. By contrast, Earth's rapid rotation, just 24 hours, breaks up global wind patterns into smaller circular systems, producing low- and high-pressure systems and hurricanes. Most of Venus's thick atmosphere, which creates 92 times the surface pressure of our own, is composed of carbon dioxide. This gives rise to a tremendous greenhouse effect and brings the surface temperature up to about 500°C (900°F). The clouds are composed primarily of sulfur compounds, most notably sulfuric acid.



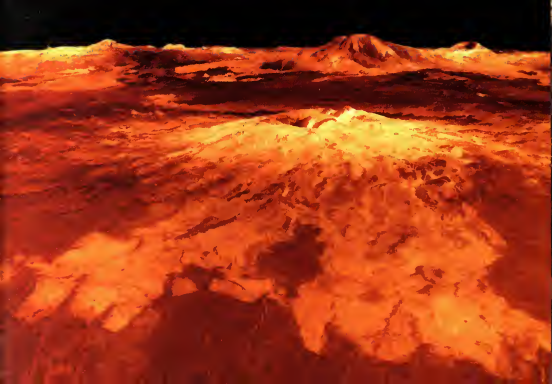


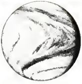
Venus: Surface
Magellan *radar image*

In 1991 the *Magellan* spacecraft mapped the surface of Venus with radar, which penetrates the planet's thick, obscuring cloud layer. This map of one hemisphere was made using data collected from the first *Magellan* mapping cycle, with missing areas filled in with data from the *Pioneer* Venus orbiter. The simulated color is based on images returned by the Soviet *Venera 13* and *14* landers. In this radar image, rough regions are bright and smooth regions are dark. The bright band running across the image is Aphrodite Terra, the largest highland region on Venus. Other areas are low, roughly analogous to ocean floors on Earth. The bright linear streaks in the center of the image represent chasms and ridges, and may be analogous to ocean trenches. The prominent bright region on the left side of Aphrodite Terra consists of a complex ridged terrain that includes rugged mountains similar to the folded mountains of Earth's Appalachian range. The small, irregular bright region along Aphrodite Terra, to the right of center, is Maat Mons, a large volcano.

Venus: Sapas Mons and Maat Mons
Magellan *radar image*

This computer-generated view of Venus was created from radar data from *Magellan*. Heights are exaggerated by approximately ten times. The bright, raised feature in the center of the image is Sapas Mons, a volcano 1.5 km (0.9 miles) high, named after a Phoenician goddess. (Venusian features are primarily named for women, real and mythical.) Sapas Mons, roughly 200 km (120 miles) across, has all of the attributes of a classic basaltic shield volcano (similar to those on the island of Hawaii), including radial lava flows, a broad, dome-like shape, and a central depression at its summit. A series of rough, bright lava flows extends hundreds of kilometers across the smooth plains in the foreground. Behind Sapas Mons, on the horizon, is another volcano, Maat Mons, approximately 1,200 km (745 miles) away. Maat Mons is steeper and lacks a depression at its summit, suggesting that it may not be a shield volcano but rather a type composed of nonbasaltic lavas. A great diversity of volcanic features, some of them unique to Venus, was observed by *Magellan* on this geologically complex planet.



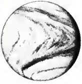


Venus: Maat Mons
Magellan *radar image*

This *Magellan* image is of Maat Mons, a volcanic mountain on Venus, named for an Egyptian goddess of truth and justice. Perspective and coloring were added in this image with the aid of a computer, creating a view from approximately 645 km (400 miles) away that could never be seen in reality due to obscuration by the thick atmosphere of the planet. In this image, bright regions are rough and dark regions are smooth. Heights, based on altimetry data (altitude measurements), have been exaggerated by approximately ten times. The mountain rises 8 km (5 miles) above the surrounding plains. The dark and light streaks that radiate from the top of Maat Mons are lava flows of varying roughness, extruded from vents at the mountain's top. The bright region in the foreground represents an extensive, rough volcanic flow, about 160 km (100 miles) long, that was extruded from Maat Mons onto the smooth, probably basaltic plains below.

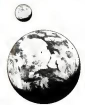
Venus: Impact Craters
Magellan *radar image*

This oblique view of three impact craters on Venus was created from *Magellan* radar and altimetry (altitude-measurement) data, with colors based on data from the *Venera 13* and *14* landers. Howe, 37 km (23 miles) across, is in the center; Danilova, 47 km (29 miles) across, is to the upper left; and Aglaonice, 62 km (38 miles) across, is to the upper right. Each crater is surrounded by a bright, rough ejecta blanket, formed by material excavated and ejected by the impact. Extensive rays, as found on the Moon, are not observed around Venusian craters, because the thick atmosphere and strong gravity prevent fine material from traveling a significant distance. The craters have central peaks, created by elastic rebound of the crust. The dark, smooth areas around the peaks that partially fill the crater floors are believed to be melted rock produced during impact. Most craters on Venus have smooth floors. The surface of Venus is so hot that very little additional heat, such as is generated by impacts, is required to melt the surface rocks. Some craters show evidence that ejecta landed partially molten.



Venus: Surface
Venera 13 *images*

These two images show the same view of the Venusian surface, taken by the Soviet *Venera 13* spacecraft with a fisheye lens, which distorts perspective. A portion of the lander is visible at the bottom of both pictures. The surface is covered with dust and small cobbles that partially cover smooth, flat volcanic rocks. A small amount of fine dust, kicked up during landing, is visible on the spacecraft. The presence of dust indicates that despite the lack of water, some sort of weathering is taking place on the surface. The top image shows the colors that would be seen by the human eye under Venusian conditions. The orange cast is created by the filtering effect of the thick atmosphere, which, like Earth's atmosphere but much more so, preferentially removes the bluer colors of sunlight. The lower image shows the same scene as it would appear under a white spotlight, revealing that the surface materials have an intrinsically gray color, typical of basalts. The *Venera* lander had equipment capable of measuring the chemical composition of the surface. The data show that at this site the surface is composed of an unusual type of basalt.



Earth Data
Distance from Sun: 149,597,870 km (92,960,116 miles)
Diameter: 12,756 km (7,927 miles)
Mass: 5.974×10^{24} kg
Density: 5.52 g/cm^3
Gravity: 9.81 meters/sec^2
Rotation: 23.93 hours
Axial Tilt: 23.4°
Sidereal Period: 365.24 days
Satellites: 1

Earth
Apollo 17 *photograph*

Images of Earth from space, such as this outstanding photograph taken by the *Apollo 17* astronauts in December 1972, reveal the beauty and fragility of our planet. This view extends from the Mediterranean Sea and the Middle East at the top to the continent of Antarctica at the south pole, with Africa dominating the center. The atmosphere, which seems so thick from our perspective, appears as a tenuous film from space. Political boundaries disappear, and it becomes clear that our planet exists as a single entity. Earth is a prototypical terrestrial-type planet, with a solid metallic core, a mantle, and a crust that bears oceans and land masses. At one time these land masses formed one gigantic continent, Pangaea, that over the aeons was broken up into separate continents by plate tectonics and other forces. Although other planets have had liquid water at some time, Earth is the only planet with oceans, which cover 71 percent of the surface of our planet and have profound effects on our weather. The oceans are among the conditions on Earth that brought about the formation of life and the evolution of species.

Earth: Hurricane
Space shuttle photograph

Since the 1960s space satellites have been used to transmit photographs of the atmosphere, record atmospheric and sea surface temperatures, track sea ice, check electron and proton activity around the planet, and track storms, such as this one, Hurricane Elena. Earth's weather patterns are influenced by a deflection of air, called the Coriolis force, caused by our planet's fast rotation. Despite the sometimes destructive effects of weather, which occurs in the troposphere within about 16 km (10 miles) of Earth's surface, our atmosphere by and large protects us. Some 99 percent of its mass is within 31 km (19 miles) of the surface. Largely composed of nitrogen and oxygen, the atmosphere also contains many other elements. It has enough carbon dioxide to insulate us from the freezing temperatures of outer space, but not enough to cause a greenhouse effect to the extent seen on Venus. Our atmosphere also prevents some types of harmful radiation from penetrating to the surface, and disintegrates most incoming extraterrestrial matter.

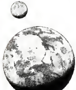
Earth: Sinai Peninsula
Space shuttle photograph

In addition to weather monitoring and communications, satellites are used to map Earth's shape and surface, including the outlines of the crustal plates, to search for mineral deposits and other resources, and to monitor agricultural areas. Such studies help scientists understand how our planet gave rise to the microorganisms that preceded us as early as 3.5 billion years ago. Earth's oceans have been key to the development of life, with water-borne photosynthesizing algae, which contributed much oxygen to the atmosphere, playing an important role. This photograph of the Sinai Peninsula and surrounding waters contrasts sharply with the topographical photographs of our terrestrial-type neighbors—Mercury, Venus, and Mars—which show barren, uninhabitable landscapes. The atmosphere around our planet protects us from the Sun's burning heat, the deep-freeze of space, and dangerous radiation. Our oceans and landmasses sustain us. Earth appears to be the only planet in our solar system with the conditions necessary to support life.

Moon Data
Distance from Earth: 384,404 km (238,869 miles)
Diameter: 3,476 km (2,160 miles)
Orbital Period: 27.32 days

The Moon: Eastern Limb
Galileo *image*

The Moon's orbit is complex, not a simple ellipse, because the Sun, the other planets, and Earth all pull on it. Because the Moon rotates on its axis in the same amount of time it takes to circle Earth, one side of the Moon always faces us. This situation is referred to as *tidal lock* or *synchronous rotation.* Actually more than half—about 59 percent—of the Moon's surface is revealed to us because of a slight oscillation of the Moon known as *libration.* The 41 percent on the opposite side, or farside, is never seen from Earth but is not the "dark side," since the Moon does rotate, exposing all parts of its surface to darkness and sunlight over a one-month period. This view, showing both farside and nearside, was photographed by *Galileo* before the "gravitational slingshot" boosts by Venus, Earth, and the Moon gave it the velocity to reach its intended target, Jupiter. The Moon's two general types of terrain are clearly visible: the dark lava seas called *maria* (singular *mare*), which are found mainly on the nearside, and *highlands,* the light-colored mountainous areas on both sides.

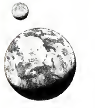


The Moon: Surface
Apollo 17 *lunar surface photograph*

Astronauts of the Apollo missions of the late 1960s through the early 1970s collected 382 kg (842 pounds) of lunar rocks, all of which were revealed to be igneous, of volcanic origin. Other forces have worked on Moon rocks, including impacts that formed the Moon's ubiquitous craters. Split Rock, shown here with astronaut Harrison Schmitt, had apparently broken loose from North Massif, a mountain near the edge of Mare Serenitatis, and rolled toward the plain below. The rock's two halves, solidified material that had melted upon a meteoric impact (probably the one that excavated the Serenitatis basin), had different appearances. The half nearest Schmitt is bluish and crystalline, with fragments of highland rock; the other half is greener and more vesicular (marked by air pockets), and contains fragments of the blue rock, evidence that it was the last of the sampled material to solidify. While the Moon lacks sedimentary and metamorphic rocks, as are found on Earth, it has its own variations of igneous rocks, shaped by the processes that have sculpted its surface.

Earth from the Moon
Apollo 11 *orbital photograph*

This image of Earth rising over the lunar surface was taken by the astronauts of *Apollo 11* shortly after they entered lunar orbit. The lifeless browns and grays of the Moon and the brilliant blues and whites of Earth contrast sharply. Earthrise can be witnessed only by orbiting the Moon or traveling along its surface, not by standing still and waiting for rotation to do the job. This is because the Moon spins on its axis at exactly the same rate as it orbits Earth (once every 27.3 days), so the same side of the Moon always faces Earth. Thus an observer on the nearside of the Moon would see our bright planet—four times the Moon's size and six times more reflective—eternally hanging in the same place in the lunar sky. Each month Earth would go through a complete cycle of phases (new, crescent, full, etc.) without ever rising or setting. (We see the Sun and the Moon rising on Earth because of our planet's rotation, once every 24 hours.) Astronauts have universally been impressed by our planet's beauty in space, a lovely blue and white that outshines the dull, gray Moon.



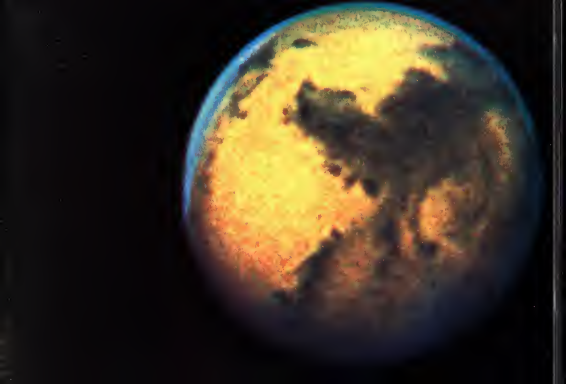
Earth and Moon: Comparison
Earth: Apollo 17; *Moon: Earth-based photograph*

Earth, with a diameter of 12,756 km (7,927 miles), is roughly four times the size of the Moon, which has a diameter of 3,476 km (2,160 miles). With the exception of Pluto and its satellite Charon, Earth and the Moon are closer in size than any other planet-satellite pair in the solar system. Venus, often called Earth's twin because of its similar size, and Mercury have no satellites at all. The other terrestrial planet, Mars, has two very small satellites that appear to be captured asteroids. Some satellites surrounding Jupiter, Saturn, Uranus, and Neptune are planet-size—some as large as or larger than the planet Mercury—but are quite small in comparison to the planets around which they orbit. Earth and its Moon are sometimes referred to as a double, or binary, planet. That Earth is a living, geologically active world covered by oceans and an atmosphere is mainly due to its size. The Moon is too small to have kept enough internal heat to sustain geological activity. Its gravity, a function of size and mass, is too weak to hold an atmosphere. Thus our Moon remains a cold, lifeless, airless world.

Mars Data
Distance from Sun: 227.94 million km (141.64 million miles)
Diameter: 6,786 km (4,217 miles)
Mass: 0.1074 × Earth's mass
Density: 3.95 g/cm^3
Gravity: 0.379 × Earth's gravity
Rotation: 24.62 hours
Axial Tilt: 25.19°
Sidereal Period: 686.98 days
Synodic Period: 779.94 days
Satellites: 2

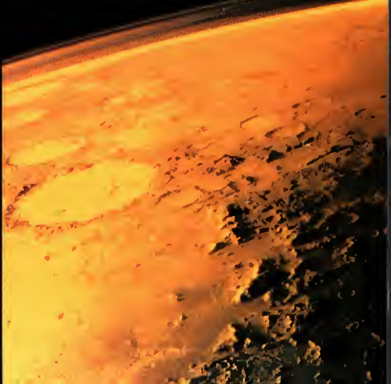
Mars
Hubble Space Telescope image

The surface color of the "red planet" is caused by the oxidation of iron-bearing minerals, i.e., rust. There has been speculation about the possibility of life on Mars, much of it based on supposed observations of "canals" on the surface. Spacecraft have revealed not canals on Mars, but a cold planet hostile to life. Its thin atmosphere (with only 1 percent the surface pressure of Earth's) is composed mainly of carbon dioxide. The pressure is too low for liquid water to exist. The large, dark, "shark fin" feature extending into the sandy orange plains in this image is Syrtis Major Planitia, a plain thought to be covered with coarse, dark sand. The bright orange region to the left is Arabia Planitia, which may be covered by a thin layer of fine reddish dust deposited by winds, while the bluish area at the far left is atmospheric haze over Mars's south polar region. When Mars is at opposition (when Earth is between Mars and the Sun), it rises at sunset and remains in the sky all night. As close as 56 million km (35 million miles) to Earth at such times, it appears orange-red to the naked eye.



Mars: Argyre Basin
Viking *orbiter image*

In the foreground of this image is the basin and rim of one of the two largest Martian impact sites, Argyre Basin, located halfway between Valles Marineris and the south polar cap. Its overall diameter exceeds 700 km (435 miles). The smooth lower-left portion of this image is most of the basin. Its jumbled mountainous rim, broadened by ejecta (material ejected by the impact), makes up the lower-right part of the frame. Such mountains, formed by impact uplifting and ejection, are unusual on Mars, most of whose mountains are of volcanic origin. The large crater at center left is Galle, with a diameter of 210 km (130 miles). The impacts that formed such craters may have been capable of ejecting rocks into the solar system, which were then intercepted by Earth. Several meteorites found on Earth have displayed chemical and physical properties that suggest they have come from Mars. Carbon dioxide haze is visible on the horizon. Mars's atmosphere is 95 percent carbon dioxide and is substantial enough to support huge dust storms, some of which cover the entire planet and generate winds of several hundred miles per hour.



Mars: Tharsis Bulge and Valles Marineris
Viking *orbiter mosaic image*

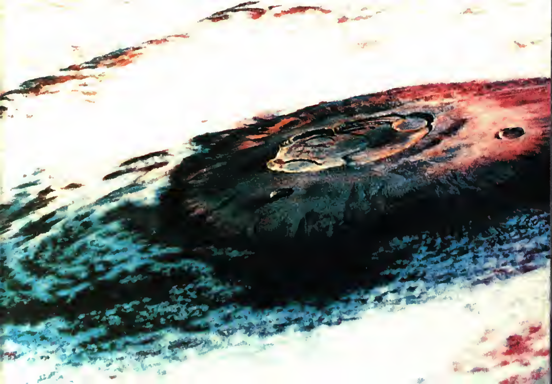
Exactly 102 *Viking* orbiter images went into the making of this mosaic of the disk of Mars. The Tharsis Bulge is a huge uplifted section of the Martian crust on which several volcanoes sit. Two of the large Tharsis volcanoes, each about 25 km (15 miles) high, can be seen on the left side: Pavonis Mons and, above it, Ascraeus Mons. Olympus Mons, the solar system's largest volcano, is beyond the horizon. In the center of the image is Valles Marineris, a huge canyon created by stresses associated with the volcanism that made the Tharsis Bulge. Valles Marineris is almost 5,000 km (3,100 miles) long, hundreds of kilometers across, and more than 6 km (4 miles) deep in places. For comparison, the Grand Canyon in Arizona is about 350 km (220 miles) long, 30 km (19 miles) across at its widest, and 2 km (1 mile) deep. Valles Marineris begins to the left (west) at Noctis Labyrinthus, a series of arcing valleys, and ends in chaotic terrain to the right. Many outflow channels, probably formed by liquid water, run from the chaotic terrain of Valles Marineris toward lower-lying regions to the north.

Mars: South Polar Ice Cap
Viking 2 *orbiter image*

Mars has two bright polar ice caps large enough to be seen from Earth through a telescope. Each polar cap has a permanent year-round component, which enlarges seasonally with the onset of winter, when temperatures drop to −140°C (−220°F). The seasonal ice cap is made up of carbon dioxide that freezes out of the atmosphere during cold weather. The permanent or residual ice caps consist of water ice in the north pole and a mixture of carbon dioxide ice (dry ice) and water ice in the south pole. A spiral pattern of dark lines, visible here in the south pole's residual ice cap, which is roughly 360 km (225 miles) across, is created by a series of valleys or southward-facing escarpments that are free of ice. The process that formed the spiral pattern—still a matter of scientific debate—may be erosion by winds spiraling away from the poles. Underneath the polar caps, sometimes visible in the ice-free valleys, is a distinctive layered terrain. The layers are believed to represent deposition of different mixtures of ice and dust resulting from variations in the Martian climate over time.

Olympus Mons
Viking 1 *orbiter image*

Olympus Mons, seen in this colorized *Viking 1* image, is a gigantic shield volcano 25 km (15 miles) high and 700 km (435 miles) across, whose summit rises above the clouds of the thin Martian atmosphere. It is the largest known volcano in the solar system. Olympus Mons and the other volcanoes of the Tharsis region are similar in appearance to the smaller shield volcanoes of the Hawaiian Islands on Earth, the largest of which, Mauna Kea, is 120 km (75 miles) across and rises 9 km (5.5 miles) above the ocean floor. Shield volcanoes have a series of craters or calderas on their summits. These are not lava vents but depressions created when the summit collapses after the withdrawal of magma from below. Lava vents are sometimes found in the central caldera, but are more often found as rift zones (cracks) along the flanks of the volcano. Olympus Mons has a series of nested calderas on its summit that form a collapsed region 80 km (50 miles) across. Impact craters can be seen near the summit caldera complex. A steep escarpment (cliff), up to 6 km (4 miles) high, surrounds the base of Olympus Mons.



Mars: Olympus Mons and Tharsis Bulge

Martian geography in perspective

An outline of the United States has been superimposed on a map of the Tharsis region on Mars. The Tharsis Bulge is a broad, high region created by a combination of upwarping of the Martian crust and large volcanic flows. The crest of the Tharsis Bulge is close to the western edge of Noctis Labyrinthus, a series of valleys arcing westward of Valles Marineris. Radially oriented fractures, including Valles Marineris, surround the Tharsis Bulge, and the largest and youngest volcanoes on Mars are associated with it. Olympus Mons, in the upper left, is the largest and youngest of all the Martian shield volcanoes. The three large Tharsis volcanoes—from bottom center to upper right, Arsia Mons, Pavonis Mons, and Ascraeus Mons—are only slightly older than Olympus Mons. All of these volcanoes have broad, low slopes typical of the fluid basalt flows of a shield volcano. Their great size indicates that they were built up from numerous flows over a very long period of time.

Mars: Dendritic Channel
Viking *orbiter image*

A variety of channels is found on the Martian surface, primary among them runoff, or dendritic, channels and outflow channels. Dendritic channels resemble terrestrial rivers and streams, with well-developed tributary networks and downstream broadening. Restricted to the oldest regions on the Martian surface, they probably formed before 3.5 billion years ago. Astronomers deduce that the atmosphere of Mars was thick enough early in its history to have created the surface pressures and temperatures needed for liquid water to exist. The outflow channels, however, do not resemble terrestrial rivers and streams. They emerge fully developed, many from the chaotic terrain east of Valles Marineris, and become wider and shallower downstream. They were apparently created quickly when large amounts of water were released, either from melted ice or an underground reservoir. They formed over a long period of time, from about 3.9 to 2.5 billion years ago, when liquid water was not stable on the Martian surface. The huge, churning, vaporizing floods must have been an astonishing sight.

Mars: "The Face"
Viking 1 *orbiter image*

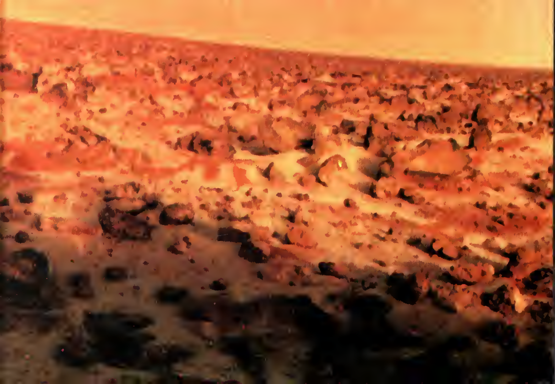
This picture, taken by the *Viking 1* orbiter in July 1976, generated great commotion among some searching for evidence of extraterrestrial life. Several books were written about the face on Mars, some of which reproduced this image with the shadows enhanced to make the face more convincing. The black specks on this image, including one that provides the face with a nostril, are artifacts of the imaging process. Close examination of the shadows in the image found that those associated with the crater near the face are circular, while the face itself is casting a rather conical shadow. This implies that the region containing the "mouth" is significantly higher than the rest of the face and supports the conclusion by scientists that the face is a natural rock formation, and that its appearance in this image is an accident of topography and Sun angle. It probably would not be visible as a face under different lighting conditions. None of the thousands of other spacecraft images, nor the *Viking* lander biology experiments, have found evidence of life, past or present, on Mars.

Mars: Surface
Viking 1 *lander image*

This image of the Martian surface was taken by the *Viking 1* lander on July 21, 1976, the day after it landed. The surface is covered by a thin layer of orange-red rust, created by the oxidation of iron-bearing minerals. Light-colored bedrock is visible running across the middle of the image. Closer to the horizon are a number of dark-colored rocks that may have been ejected from a nearby impact crater. On the horizon is a rocky ridge that may mark the rim of another impact crater. Dark-colored soil is exposed in patches, such as that around the large rock in the lower-right corner, and the surface is littered with pitted rocks. The pits, or vesicles, are typical of a basaltic lava composition. Similar landscapes, some of them also reddish in color, can be found in Hawaii and Iceland. A color chart on the *Viking* lander was used to correctly calibrate color in the image it recorded. The Martian sky was discovered to be salmon pink, an effect caused by the scattering and reflection of light off reddish-colored, micron-size dust particles from the surface suspended in the atmosphere.

Mars: Surface in Winter
Viking 2 *lander image*

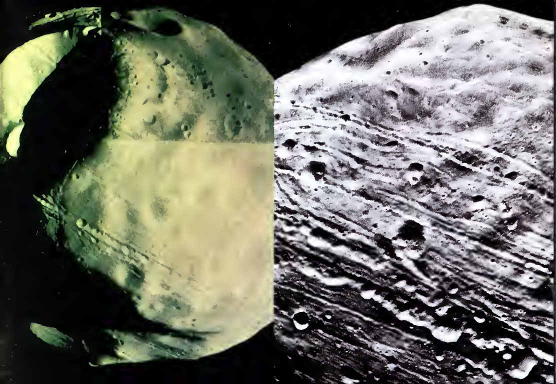
This view of the Martian surface in winter was taken by the *Viking 2* lander, which set down on the other side of Mars from *Viking 1* at a latitude of 48°, in a region far enough north for frost to form during cold weather. The frost is believed to be a mixture of carbon dioxide ice (dry ice), water ice, and dust particles. The frost disappears, or sublimes (goes directly to gas from solid form), in stages. Some of the frost, believed to be carbon dioxide, sublimes quickly after the deposition of the frost. The remainder of the frost, believed to be water ice, sublimes more slowly. It is assumed that dust is a component of the frost because after the frost disappears, the surface appears lighter in color than it was before frost deposition. Apparently the ices form on suspended dust particles, which then become heavy enough to fall to the surface. The images from the *Viking 2* lander are at an angle because the spacecraft set down with one leg on a rock. The rocks at the *Viking 2* landing site are more uniform in size and appearance than those at the *Viking 1* site.



Phobos Data
Distance from Mars: 9,380 km (5,830 miles)
Diameter: 27 × 19 km (17 × 12 miles)
Orbital Period: 0.32 days

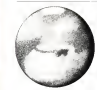
Phobos: Crater Stickney and Surface Grooves
Viking *orbiter images*

Mars has two small, irregularly shaped moons, Phobos and Deimos, named for the two horses, Fear and Panic, that drew Mars's war chariot. These puny satellites lacked the gravity needed to pull themselves into the spherical shapes seen in planets and larger moons. Both are very dark, and their spectra resemble those of carbonaceous (carbon-rich) asteroids. Mars resides at the inner edge of the asteroid belt, and it seems likely that Phobos and Deimos are asteroids that were gravitationally captured by Mars. Phobos, the larger—27 km (17 miles) across in its longest dimension—is the nearer of the two to Mars. Its surface is covered with impact craters, the largest of which is Stickney, 10 km (6 miles) in diameter (left photo). The impact that formed Stickney was almost large enough to shatter Phobos. The grooves that streak the moon's surface (right photo) probably owe their origin to the Stickney impact. Most likely they either represent deep fractures that resulted from an impact that almost fragmented Phobos, or were caused by secondary impacts from material ejected by the Stickney impact.



Phobos in front of Mars
Phobos 2 *image*

Just 9,380 km (5,830 miles) from Mars, Phobos completes one orbit of its parent planet every 7.7 hours. This image, taken by the Soviet spacecraft *Phobos 2,* demonstrates the striking difference in the colors and albedos (reflectance) of Phobos and Mars (background). Phobos is very dark, reflecting only 4 percent of the sunlight that falls on it, suggesting it may be a captured carbonaceous asteroid. The *Phobos 1* and *2* spacecraft were launched in 1988 with the prime objective of studying Phobos. Contact was lost with *Phobos 1* en route. *Phobos 2* reached Mars in 1989 and entered orbit. It measured the planet's weak magnetic field, which was found to interact with the interplanetary magnetic field of the Sun, enabling the solar wind to strongly energize atoms in the upper Martian atmosphere. This energizing activity was enough to eject atoms from Mars's outer atmosphere, suggesting that the magnetic field may be at least partly responsible for the loss of atmosphere from Mars. Just before the launching of a lander to Phobos, radio contact with *Phobos 2* was lost.

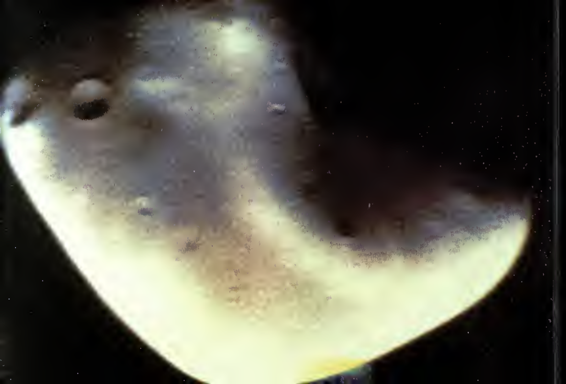


Deimos Data
Distance from Mars: 23,500 km (14,600 miles)
Diameter: 15 × 11 km (9 × 7 miles)
Orbital Period: 1.26 days

Deimos

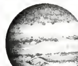
Viking *orbiter image*

Deimos, the smaller and more distant of Mars's two moons, is about 15 km (9.3 miles) across at its longest dimension and circles that planet every 1.3 Earth days. Because Phobos and Deimos are similar in size and color, and both are believed to be captured carbonaceous asteroids, scientists expected that their surface appearances would be similar. The *Viking* spacecraft found otherwise. Phobos has sharply defined craters and long linear grooves, while Deimos is much smoother in appearance. Its craters are partially buried under loose impact debris, giving it a softened, blurry overall look. Evidence shows that loose material moves in a downslope direction on a global scale on Deimos. Many of its craters are completely filled, with only their upslope rims visible. It is unclear why material on Phobos has not moved on a global scale, although local downslope movement has occurred. There is some speculation that this variation in debris flow may be due to an intrinsic initial difference in surface roughness between the two moons.



Asteroid Ida and Satellite Dactyl
Galileo *image*

Only the second asteroid to be photographed close-up by a spacecraft, asteroid Ida and its satellite Dactyl were imaged in 1993 by the *Galileo* spacecraft as it crossed the asteroid belt on its way to Jupiter. Some asteroid types, such as metallic (M-type) or carbon-rich rock (C-type), are believed to correspond to materials known on Earth. Ida, about 56 km (35 miles) long, is an S-type asteroid, the composition of which is still debated. Analysis of data gathered by *Galileo* may help to resolve the issue. Ida is a member of the Koronis family of asteroids. Many asteroids orbit the Sun in families, which are groups of asteroids that may represent pieces of a larger asteroid that was fragmented. The satellite, which is about 1.5 km (1 mile) across, is a slightly different color than Ida, suggesting that the two objects may be made of different materials. This implies that the smaller body might have been captured by Ida rather than broken off from it. Ida's irregular shape is typical of smaller solar system objects, whose gravity is too weak to round them out.



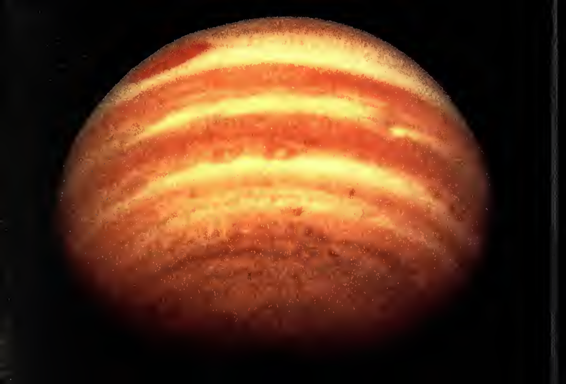
Jupiter Data
Distance from Sun: 778.33 million km (483.65 million miles)
Diameter: 142,800 km (88,735 miles)
Mass: 318 × Earth's mass
Density: 1.33 g/cm³
Gravity: 2.4 × Earth's gravity
Rotation: 9.84 hours
Axial Tilt: 3.08°
Sidereal Period: 11.86 years
Synodic Period: 398.99 days
Satellites: 16

Jupiter
Voyager 1 *image*

Jupiter, seen here from a distance of 30 million km (18 million miles), is the largest planet in our solar system, with a diameter 11.2 times that of Earth. It has at least 16 satellites, four of them larger than Pluto. Jupiter is composed mostly of hydrogen and helium, with small percentages of methane, ammonia, water, and many other compounds. It has no distinct surface but is thought to have a rocky, metallic core at its center, perhaps 1.5 times the diameter of Earth and 10 to 15 times more massive. Jupiter's atmospheric pressure at the core may be more than 100 million times that of Earth. Astronomers believe that electrically conductive, liquid "metallic" hydrogen extends out to several Earth diameters beyond the core. This hydrogen, along with the planet's rapid rotation, explains Jupiter's strong magnetic field. Jupiter's synodic period is about 13 months. It is visible in our morning sky for five months and in our evening sky for five months. At its brightest, at opposition, it reaches a magnitude of −2.5.

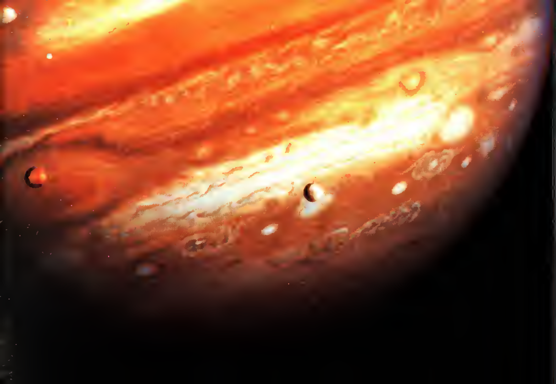
Jupiter: South Polar Region
Pioneer 11 *image*

This 1974 *Pioneer 11* photograph was taken at a unique perspective. Telescopic and spacecraft views of Jupiter had always been from a perspective very near Jupiter's orbital plane and hence its equatorial plane, since Jupiter's axis is tilted by only 3.08°. The polar regions are usually observed at an oblique angle. *Pioneer 11* passed by Jupiter at a higher inclination than any other mission; it became the first spacecraft to be ejected out of the plane of the solar system into interstellar space. The Great Red Spot, a swirling storm in Jupiter's southern hemisphere about twice the diameter of Earth, is obvious here, but what is of real interest is the breakdown of the latitudinal belts that are so distinct closer to the equator. Astronomers observed that near the poles material wells up at distinct spots, without being stretched into bands by the planet's fast rotation. Lateral (east-west) and rotational motion at higher (polar) latitudes is slower than near the equatorial belts, a property called differential rotation. Jupiter's equatorial regions rotate in 9 hours 50 minutes. The polar rotation is about five minutes slower.



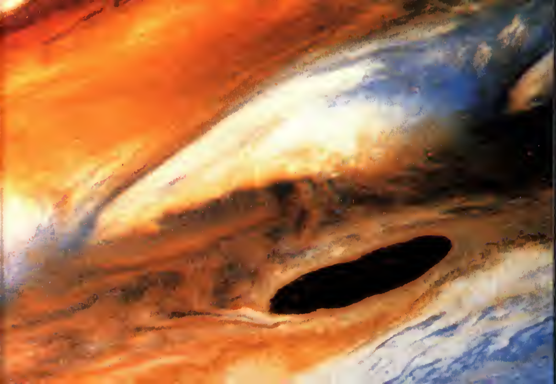
Jupiter: Southern Hemisphere and Two Moons
Voyager 1 *close-up view*

Jupiter's banded atmosphere, seen here in more or less true color, though greatly exaggerated for clarity, provides a dramatic backdrop for two of its Galilean satellites. The Great Red Spot appears behind Io (left), while Europa (right) partially obscures one of the many white ovals. The Great Red Spot is the one of the most notable features of the jovian atmosphere. Recent studies suggest that the spot, observed for at least 300 years, is a permanent feature, an enormous anticyclonic (high-pressure) storm, driven by energies within it and by the planet's rapid rotation, the fastest in the solar system. The array of smaller, white ovals spaced evenly in longitude around Jupiter at about the apparent latitude of Europa are also huge anticyclonic storms; their chemistries and temperatures result in their white color. The color differences seen throughout the jovian atmosphere are a function of variable pressures and temperatures acting on different elements and compounds; pressure and temperature vary with altitude, as on Earth.



Jupiter: Close-up of Brown Oval
Voyager 1 *image*

This elongated cloud feature, known informally as the Brown Oval, is much smaller than the Great Red Spot and many of the white ovals. Such "small" features of the jovian atmosphere are many times larger than weather patterns in our own atmosphere, but are difficult to study because of Jupiter's great distance from Earth. The Brown Oval is thought to be a hole or a clear region in the upper cloud deck of Jupiter's atmosphere that allows a deeper, warmer, and perhaps chemically distinct atmospheric layer to show. Besides the dark central region of the oval, another distinctive feature is the surrounding orangish cloud, quite unlike the usual, mottled-appearing background clouds at this latitude. The *Galileo* spacecraft, the first to photograph asteroids close-up, should provide added information about the jovian atmosphere after its arrival at Jupiter in 1995. Rather than fly by the planet as the *Pioneer* and *Voyager* spacecraft did, *Galileo* will orbit Jupiter for two years. It will also send a probe into the atmosphere, which will relay data while it descends until crushed by the increasing pressure.



Jupiter's Galilean Satellites
Size comparison of the seven largest natural satellites

This montage shows the largest natural satellites in the solar system to scale: Jupiter's Galilean satellites Io, Europa, Ganymede, and Callisto; Saturn's Titan; Neptune's Triton; and our own Moon. These are truly planet-class objects. All of them are larger than Pluto, and Ganymede and Titan exceed Mercury in size. Two, Io and the Moon, are Earth-like in composition, primarily rock and iron. Europa is a transitional object, a rocky core with a thick surface layer of water ice. The others are the principal members of a new class of "planet" (which includes Pluto): the icy satellites. These objects are about half rock/iron and half water ice, plus small amounts of many other ices, such as carbon dioxide, methane, and ammonia ice. In the smaller icy satellites in which melting has not occurred, the ice and rock are blended together. In the larger members that have experienced melting, low-density icy lavas have flowed to the surface and formed crusts composed primarily of water ice. These icy lavas are analogous to rocky lavas on Earth-like bodies, such as the dark, rocky lava seas on the Moon.


EUROPA
TRITON
IO
MOON
GANYMEDE
CALLISTO
TITAN

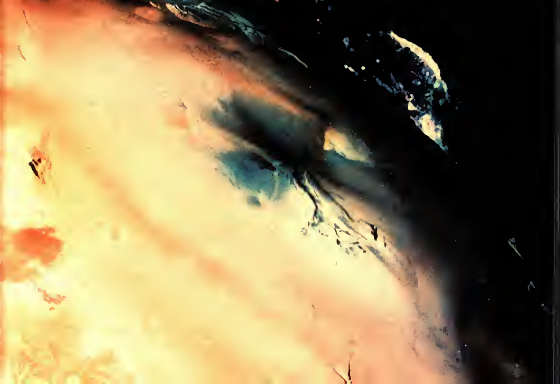
Io Data
Distance from Jupiter: 422,000 km (262,230 miles)
Diameter: 3,632 km (2,257 miles)
Orbital Period: 1.77 days

Io: South Polar Region
Voyager 1 *image*

Io is the innermost of Jupiter's Galilean satellites, which were discovered by Galileo in 1610, though not named by him. Astronomers were stunned when *Voyager 1* flew by Io in 1979 and sent back images of eight erupting volcanoes. The black spots in this photograph are volcanoes; flow fronts are also readily apparent. It is now clear that little Io is the most geologically active body in the solar system. The surface is so young—constantly renewed with material from the moon's interior—that not a single impact crater has yet been found. Because Io is not all that large (3,632 km/2,257 miles in diameter), this activity was puzzling. Smaller objects have a greater surface area relative to volume, enabling them to radiate heat more effectively than larger objects, so they usually cannot sustain an interior heat source without some outside source of energy. That energy source is a product of Jupiter's immensely powerful gravity field, coupled with that of neighboring Europa. Both pull on Io, causing tidal action on the satellite—squeezing and flexing—which leads to internal friction and heating.

Io: Volcanic Eruption
Voyager 1 *image*

This striking photograph displays a volcanic eruption on Io. The volcanic caldera is the dark region near the center of the image. Ejected material, lit by the Sun, can be seen rising off the limb of the satellite to a height of about 300 km (185 miles). Most of this material falls back to the surface of Io, forming a roughly circular apron around the caldera. Evidence from the Voyager missions suggests that the surface of Io is predominantly sulfur salts that have been raised to various temperatures. At the highest temperatures sulfur becomes black, the shade of the volcanoes, where heat would be most intense. But infrared studies over the past decade, and reanalysis of Voyager data, indicate that Io's mysteries are far from solved. The black material near the caldera and its associated flow channels may contain basaltic material, which is also very dark. This means that Io is probably hot enough to melt silicate rock, which has a higher melting point than sulfur, into basaltic flows. Astronomers are beginning to think that Io is more energetic than the tidal flexing theory can account for.



Europa Data
Distance from Jupiter: 670,900 km (416,900 miles)
Diameter: 3,130 km (1,945 miles)
Orbital Period: 3.55 days

Europa
Voyager 1 *image*

Europa is the smallest of the four large satellites of Jupiter first spotted by Galileo in 1610. It has the smoothest surface of all the satellites known in the solar system. The composition of its surface is largely water ice, while measurements of the overall density of the satellite suggest it is a primarily rocky body. It is thought that in the distant past Europa's icy crust was either liquid or heated to very close to the melting point of water, before freezing solid. After the surface froze, decay of radiogenic elements in the interior heated the rocky interior, which expanded. The ice was stretched and developed the extremely complicated global pattern of stress fractures seen in this image and the next one. Liquid water may have percolated up through the cracks, eradicating any craters that may have accumulated. The surface effectively was one solid ice floe. Subsequent cooling of the satellite caused the ice layer to expand, sealing most cracks from further leaks. Heat generated by tidal flexing may play a continuing role in keeping the ice soft and the surface smooth.

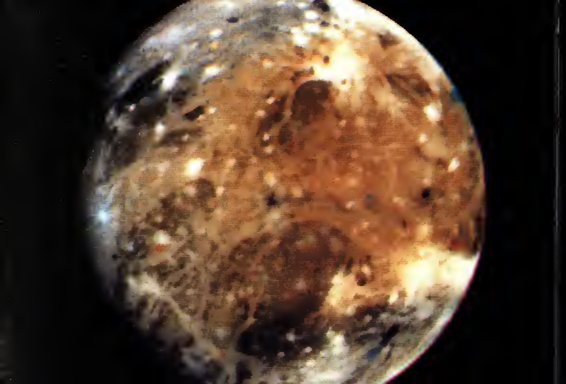
Europa: Surface
Voyager 2 *image*

This *Voyager 2* image of Europa's surface shows the intricate global network of cracks and fissures. It also reveals a distinct lack of impact craters, evidence that the surface is rather young geologically. The acute lack of such topographical features as mountains and valleys supports the young surface hypothesis, and hints that the ice is not very strong—and therefore not much colder than freezing. The blanket of ice is thought to be about 100 km (60 miles) thick. Some of the surface cracks measure more than 1,000 km (600 miles) in length. The arcuate (curved) appearance of the larger cracks is consistent with what might be expected when a spherical shell, rather than a flat sheet, is fractured. The colors apparent here may be a result of intersatellite dusting from neighbor Io's volcanism, but as attempts to represent true colors in such images are uncertain at best, this is only a supposition. Another theory is that it is "dirty" ice and water upwelling from Europa's interior. The area photographed in this image measures approximately 1,700 by 950 km (1,050 by 600 miles), equivalent to the area of the southeastern United States.

Ganymede Data
Distance from Jupiter: 1.07 million km (665,000 miles)
Diameter: 5,276 km (3,278 miles)
Orbital Period: 7.16 days

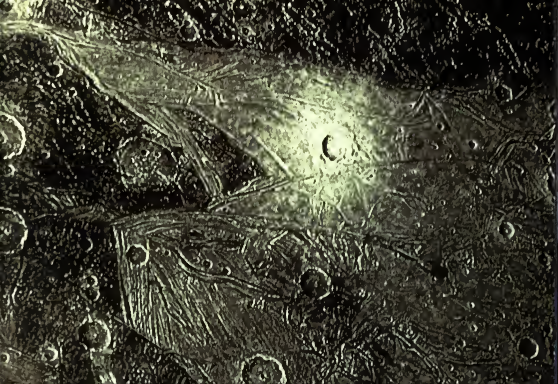
Ganymede
Voyager 1 *image*

Jupiter's satellite Ganymede has a complex surface of both light and dark areas, evident even in this distant view. Spectral readings show a surface composition primarily of water ice, indicating that during its history Ganymede has been covered by icy lavas. Surface flows of liquid material result from internal melting. It is believed that all bodies in the solar system have some internal heating due to radioactive decay of naturally occurring uranium, thorium, and potassium. All other conditions being equal, larger bodies will get hotter inside than smaller bodies for a given heat source and will experience greater internal melting. Thus Ganymede, the largest of the icy satellites, should have experienced the most melting and resurfacing. Smaller icy bodies should show less resurfacing and thus be more heavily cratered since all bodies were covered by impacts during their formation. Although it may seem to contradict this theory, Ganymede's surface is much more extensively resurfaced than larger Mercury's. This is because Mercury's lavas are made of rock, which have much higher melting points than icy lavas.



Ganymede: Surface
Voyager 2 *image*

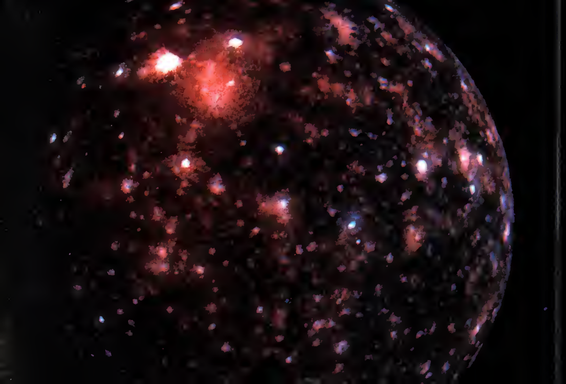
This image shows the light and dark terrains on Ganymede in more detail. The light terrain consists of bright plains of smooth and lineated or grooved materials. The dark regions are rugged plains with numerous craters and long, arcuate furrows. The boundaries between the light and dark terrains are very sharp, and where it can be determined, the light terrain lies slightly lower than the dark. These relations indicate that the light terrain was formed by icy floods filling in fractured and down-dropped sections of dark terrain. The dark terrain is somewhat more heavily cratered than the light, implying a greater age, but the numbers of craters per unit area on the dark terrain is less than one-third the maximum possible number (achieved on Callisto), suggesting that the original heavily cratered surface has been buried to an unknown depth by darker icy lavas. The surface structures seen here are made of water ice. Terrestrial experience suggests that water ice features should flow and flatten like glaciers. That has not occurred here: At Ganymede's temperatures (-153°C/-216°F), ice is just as rigid as rock is on Earth.



Callisto Data
Distance from Jupiter: 1.88 million km (1.17 million miles)
Diameter: 4,820 km (2,995 miles)
Orbital Period: 16.69 days

Callisto
Voyager 2 *image*

Callisto, Jupiter's second-largest satellite, has nearly the same composition as its slightly bigger neighbor Ganymede. Theories about planetary evolution predict that these two large satellites should have similar surface features and should show extensive volcanism and fracturing and relatively few impact craters. While most planets and satellites in the solar system fit the theoretical model, Callisto is the outstanding exception. As can be seen in this false-color image, Callisto's surface is smothered with impact craters. Indeed, the density of craters on Callisto is near the theoretical maximum, indicating a virtual absence of interior activity since their formation. The conspicuous bright splotches on Callisto's dark, low-reflecting surface are the rays of fresh craters. The largest, roughly circular pattern pictured is one of several giant ringed structures on Callisto that are probably large impact basins. Callisto, in contrast to Ganymede, has no known features that are unrelated to impact craters. Many explanations have been proposed to account for Callisto's apparent internal inactivity, but it continues to challenge astronomers.



Callisto: Valhalla Basin
Voyager 1 *image*

This *Voyager 1* photomosaic shows the Valhalla Basin, a splendid example of a type of icy ring structure found only on Callisto and Ganymede. These structures consist of roughly circular central plains (sometimes highly reflective, as shown here) surrounded by rings of ridges in a concentric pattern. The largest examples, as here, have an additional annulus of concentric cliffs and valleys. In Valhalla's case, this outer annulus consists of numerous cliffs facing away from the center of the structure. Several of the cliffs have smooth light or dark strips along their bases, probably small amounts of extrusive flow from Callisto's interior. The leading hypothesis is that these structures are giant impact craters formed when the interiors of Callisto and Ganymede were warm and plastic. The initial impact produced a deep cavity and caused a strong inward flow of subsurface material. The flow fractured the cold, brittle surface at large distances and then compressed the surface into ridges where it welled up into the original crater cavity. The Valhalla structure extends to a diameter of 3,000 km (1,860 miles).

Amalthea Data
Distance from Jupiter: 181,300 km (112,660 miles)
Diameter: 270 × 155 km (170 × 95 miles)
Orbital Period: 0.49 days

Amalthea
Voyager 1 *image*

Four smaller moons orbit between the four Galilean satellites and Jupiter, and at least eight lie farther out. As the largest of Jupiter's moons, easily visible from Earth, the Galilean satellites have been objects of study since their discovery in 1610. It wasn't until 1892 that astronomer E. E. Barnard discovered a fifth satellite, which he named Amalthea. Tiny Amalthea, inward from the Galilean satellites, zips around Jupiter in 11.7 hours and is deeply immersed in the planet's intense radiation belts. Measuring only 270 km by 155 km (170 by 95 miles), Amalthea is too small to have enough self-gravity to pull itself into a spherical shape. The long axis always points toward Jupiter. Amalthea's rocky surface, with a reflectivity of only about 10 percent, is reddish. This coloration is thought to be to a coating of sulfur from the volcanically active moon Io, for in the intense charged-particle environment of Jupiter, sulfur assumes a reddish color. Amalthea's close proximity to its bright parent planet makes it difficult to study from Earth. *Voyager 1* took this image at a distance of 425,000 km (264,000 miles).

Saturn Data

Distance from Sun: 1,426.98 million km (886.73 million miles)
Diameter: 120,660 km (74,980 miles)
Mass: 95.15 × Earth's mass
Density: 0.69 g/cm^3
Gravity: 1.06 × Earth's gravity
Rotation: 10.23 hours
Axial Tilt: 26.4°
Sidereal Period: 29.46 years
Synodic Period: 378.09 days
Satellites: 18

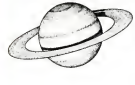
Saturn: Close-up with Rings

Voyager 2 *image*

The second-largest planet in our solar system, Saturn is of such low density it would float in water. It is thought to have a small core of rock and ice, an inner layer of metallic liquid hydrogen, and a gaseous hydrogen and helium atmosphere. Its exterior displays a banded system of clouds, running parallel to the equator like that of Jupiter. These bands are a function of Saturn's fast rotation (10.2 Earth hours) and its strong internal heat source. Two of Saturn's 18 known satellites are apparent in this global mosaic, one as a pinpoint of light, a second casting a shadow on the planet's surface. Saturn's satellites are mainly rocky, icy bodies. Nine of them were known from Earth-based observation, and the remainder were discovered by *Voyager 1* and *2* in 1980 and 1981. A number of the smaller satellites are shepherd moons that accompany the rings in orbit and appear to help them maintain their shape. Some of Saturn's rings, composed mainly of rocky chunks of ice, can also be seen in this image, with the low-density area called the Cassini Division quite prominent.

Saturn and Rings
Voyager 1 *image*

Saturn is a thrilling sight, even in Earth-based telescopes. This *Voyager* image, obtained in 1980 as the spacecraft approached the planet, shows the classical view at a resolution higher than anything obtainable from Earth, even with the best telescopes. The muted appearance of Saturn, as compared to Jupiter, is a function of Saturn's lower temperatures, which give the planet a thicker, more-obscuring upper cloud deck. Saturn is visible in our skies most of the year: in the evening when at eastern quadrature, in the morning when at western quadrature. It moves so slowly—taking 29.5 years to make one full revolution around the Sun—that it stays among the stars of the same constellation for two years. It is visible to the naked eye, and its rings can be seen in amateur telescopes. Because of Saturn's axial tilt, the rings are sometimes tilted toward us and are quite bright and at other times are edge-on and become invisible from Earth. They are less than 500 meters (1,600 feet) thick but extend out 140,000 km (87,000 miles).



Saturn: Crescent and Rings
Voyager 2 *image*

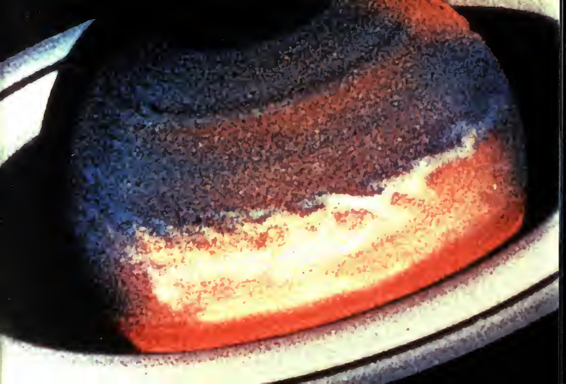
This view of Saturn shows the solar system's second-largest planet from a perspective that cannot be attained from Earth. It was taken after the *Voyager 2* spacecraft had passed Saturn, looking back toward the Sun. This image of the ringed planet as an uncustomary crescent is both intriguing and scientifically valuable. By comparing this image, with the ring in "forward-scattered" light (the reflected sunlight is directed away from the Sun), with others taken in "back-scattered" light (sunlight reflected back toward the Sun and Earth), astronomers were able to determine the distribution of particle sizes in the rings. The size distribution of aerosol particles in Saturn's upper atmosphere can be determined in a similar manner. The rings are revealed to be somewhat transparent in this image, as the planet can be seen right through them, and their shadow on the planet is not completely black. Astronomers are also able to get an indication of the height distribution of Saturn's cloud tops from such images, based on the smoothness of the terminator (the dividing line between the illuminated and dark hemispheres).

Saturn: Atmospheric Close-up
Voyager 1 *image*

The atmosphere of Saturn appears very similar to that of Jupiter, but is less colorful and defined, mainly because Saturn is cooler than Jupiter, owing to its greater distance from the Sun and because it puts out less internal energy. Saturn's cool upper atmosphere allows the freezing out of ammonia crystals at high altitudes, creating a haze layer that veils the cloud structure below. Because the ammonia haze layer is more opaque on Saturn than on Jupiter, chromophores (colored chemical agents) are seen much less distinctly. Saturn's cloud patterns, like Jupiter's, tend to be aligned in bands parallel to the equator, largely due to the fast rate of rotation. Saturn also shares with Jupiter (and with the Sun) its basic composition: almost entirely hydrogen and helium. Methane, ammonia, and other chemical compounds, mostly hydrocarbons, as well as a small amount of rock, make up the rest.

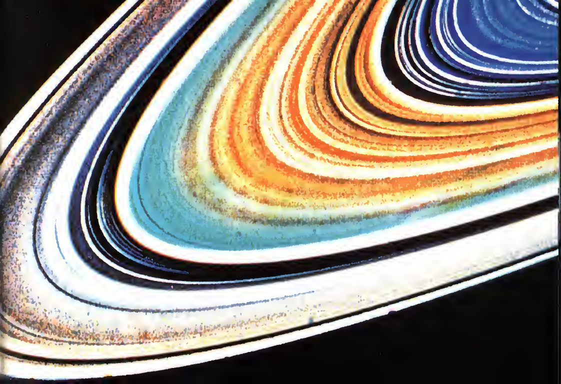
Saturn: Atmospheric Storm
Hubble Space Telescope image

In late 1990, an amateur astronomer spotted the eruption of an immense storm near Saturn's equatorial region. The Hubble Space Telescope was then pointed at Saturn to record the development and subsequent dissipation of this feature. This image, heavily processed to enhance contrast and partially corrected for Hubble's then-blurry vision, shows the storm as a white band near the planet's equator. Within weeks, wind shear in the atmosphere had torn the white region apart, spreading it around the entire girth of the planet at that latitude. Saturn's equatorial winds are severe, while the winds at higher latitudes are much more tranquil. This latitudinal velocity difference is much greater on Saturn than on Jupiter. In fact, Saturn's equatorial winds travel at a good fraction of the speed of sound, as shown by *Voyager.* The historical record shows that similar storms appear on Saturn roughly every 30 years or so, which (perhaps coincidentally, perhaps not) is how long Saturn takes to complete one orbit around the Sun. This suggests that such storms may be a seasonal phenomenon of Saturnian weather.



Saturn: Close-up of Rings
Voyager 2 *image*

This false-color view of Saturn's rings was taken by *Voyager 2* about 8.9 million km (5.5 million miles) from the planet. The color differences displayed here are mainly a function of the size of the ring particles, which affects how they scatter light. The particles are about 10 cm in diameter on average, but range from dust-size to house-size. The green- and orange-hued regions have larger particles than average; the inner blue-colored regions have smaller ones. These particles are unable to accrete together to form satellites because the planet's pull is so much stronger than that of the particles on one another. Clearly visible in this image is the dark Cassini Division (about two-thirds of the way out), dividing the outer A ring from the B and C rings. Once thought to be completely free of orbiting debris, the Cassini Division is an area in which the particles are sparsely distributed. Some images of Saturn show radial "spokes" in the rings, probably shadows of ice "dust" (produced by particles grinding against each other) electrostatically elevated above and below the ring plane.

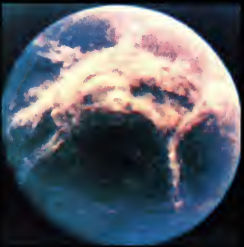


Mimas Data
Distance from Saturn: 185,500 km (115,300 miles)
Diameter: 390 km (240 miles)
Orbital Period: 0.94 days

Dione Data
Distance from Saturn: 377,400 km (234,500 miles)
Diameter: 1,120 km (695 miles)
Orbital Period: 2.74 days

Mimas and Dione
Voyager 1 *images*

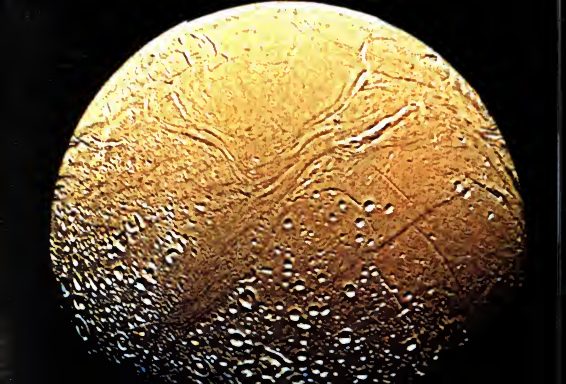
Mimas (left), the innermost of Saturn's large satellites, is a heavily cratered ice-rock ball less than 400 km (250 miles) in diameter. Its largest crater, Herschel (upper right), has a diameter of 140 km (90 miles) and is about 10 km (6 miles) deep. Its central peak rises about 6 km (4 miles) high. Early suggestions that the Herschel Crater impact caused the surface fractures all over Mimas have been discounted. The energy of the impact would have been too weak to fragment Mimas. The narrow fractures are probably the result of mild internal heating. Dione (right), at 1,120 km (695 miles) in diameter, is larger than Mimas and shows much more evidence of geological activity driven by internal heating. This image of Dione is dominated by bright, curving, wisplike streaks. Although the streaks seem to be associated with the large crater Amata, near the center of the image, they are not ejecta (ejected material) from this crater. They appear to emanate from sets of fractures crossing the surface and are probably condensed volcanic gases that erupted from the fractures.

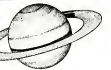


Enceladus Data
Distance from Saturn 237,900 km (147,830 miles)
Diameter: 500 km (300 miles)
Orbital Period: 1.37 days

Enceladus
Voyager 2 *image*

Saturn's moon Enceladus is located in the center of the diffuse E ring, which consists of tiny spherules of water ice, and its surface is coated with these particles, making it the most reflective satellite in the solar system. A large portion of its surface is pocked with impact craters that originate from the satellite's final stage of formation. Other portions of the surface are crater-free, covered with smooth plains, canyons, cliffs, and icy lava flows, indicating a young surface and an active interior. The spearhead-shaped smooth area that nearly divides the cratered surface offers evidence that the craters came first. Some of the craters along this area are cut in half, and some have tongues of the smooth material extending onto their floors. The particles that form the E ring and that brighten Enceladus's surface also may be products of ongoing water volcanism. Only slightly larger than Mimas, Enceladus is too small to have generated enough internal radioactive heat to cause the evident fracturing and volcanism. Enceladus's heat, like that of Jupiter's Io, is thought to result from tidal forces caused by the gravity of Saturn and the moon Dione.



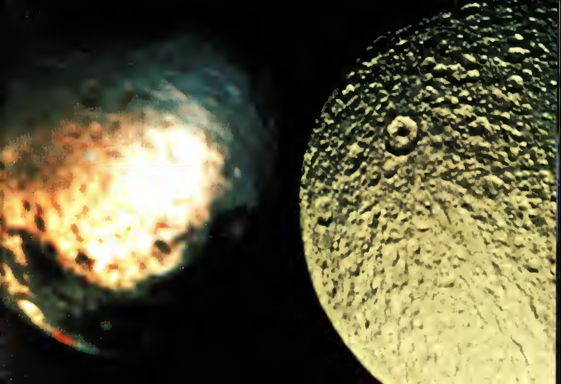


Iapetus Data
Distance from Saturn: 3.56 million km (2.21 million miles)
Diameter: 1,440 km (895 miles)
Orbital Period: 79.33 days

Tethys Data
Distance from Saturn: 294,700 km (183,125 miles)
Diameter: 1,050 km (650 miles)
Orbital Period: 1.89 days

Iapetus and Tethys
Voyager 2 *images*

Saturn's moon Iapetus (left) shows the greatest large-scale contrast in surface brightness in the solar system. The bright trailing side has a reflectivity comparable to week-old snow, while the dark leading side has a reflectivity similar to that of coal. Spectral analysis indicates that the dark material is a black, carbon-bearing substance common in some meteorites. It may have originated from Iapetus's dark neighbor Phoebe, or it may be dark material that emerged from the interior. The surface of Iapetus is mostly covered by impact craters, but some large cliffs and canyons, barely visible across the center of this image, indicate internal geologic activity in the past. Tethys is also heavily cratered but shows signs of significant internal heating in the past. The area around the craters near the center is smoother than elsewhere, indicating icy volcanic flooding. The spectacular Ithaca Chasma, a system of canyons 20 to 50 km (12–30 miles) wide and up to 5 km (3 miles) deep, extending about 270° around the surface, was probably caused by internal heating and expansion.



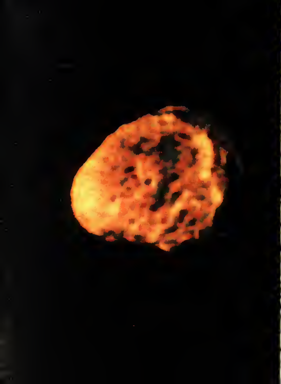
Hyperion Data
Distance from Saturn: 1.481 million km (920,300 miles)
Diameter: 350 × 200 km (220 × 125 miles)
Orbital Period: 21.28 days

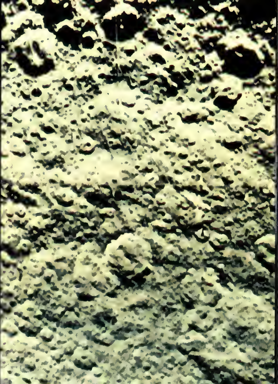
Rhea Data
Distance from Saturn: 526,700 km (327,300 miles)
Diameter: 1,530 km (950 miles)
Orbital Period: 4.52 days

Hyperion and Rhea

Hyperion: Voyager 2; *Rhea:* Voyager 1

With an average diameter of about 300 km (190 miles), the Saturnian moon Hyperion (left) is among the largest irregularly shaped objects in the solar system. Hyperion appears quasi-circular in this image (with a few large chunks missing), but other images show that it is shaped like a rugged hockey puck, which in this image we see nearly face-on. The surface is heavily cratered, and the few arcuate ridges and the circular "bite" out of the satellite's edge at bottom are probably the outlines of huge craters almost as large as Hyperion itself. Rhea (right) is the largest of Saturn's middle-size icy satellites. This *Voyager 1* mosaic of Rhea's north polar region has a resolution of about 1 km (½ mile), showing very fine detail on the surface. The surface is fairly heavily pitted with small craters but very few large ones. The large craters, of which the most prominent is Ormazd (150 km/95 miles in diameter), near the center of the mosaic, appear battered and subdued in outline. Rhea's surface is also covered by a network of long but low ridges and cliffs, and chains of overlapping pits, all of internal origin.

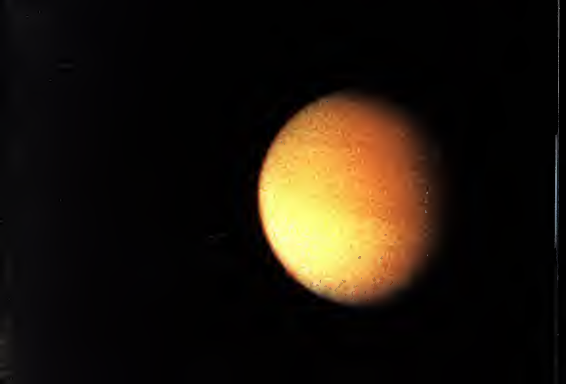




Titan Data
Distance from Saturn: 1.222 million km (759,350 miles)
Diameter: 5,150 km (3,200 miles)
Orbital Period: 15.95 day

Titan
Voyager 1 *image*

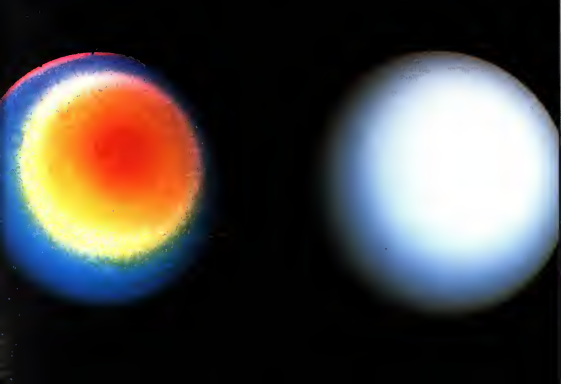
Saturn's fascinating moon Titan is the second-largest planetary satellite in the solar system and the only one with a thick atmosphere. The atmosphere is so thick and cloudy that it completely obscures the surface, as in this 1980 *Voyager 1* image. The darkening of the surface toward the sunset line at right is caused by the scattering of light from deep cloud or haze layers. The southern hemisphere appears brighter here than the northern, and the northern polar area appears darker than the northern mid-latitudes. Lower resolution images of Titan taken in 1992 with the Hubble Space Telescope showed the northern hemisphere brighter than the southern. Since the images were taken about half a Titan year apart, it is thought that they recorded changes in cloud patterns due to seasonal shifting of winds. Titan's atmosphere, like ours, is composed mostly of nitrogen, but its next most abundant gases are methane and carbon monoxide. Thus Titan's clouds and hazes are made of tiny particles of sunlight-altered nitro/methane compounds—that is, smog.



Uranus Data
Distance from Sun: 2,870.99 million km (1,784 million miles)
Diameter: 51,118 km (31,765 miles)
Mass: 14.531 × Earth's mass
Density: 1.24 g/cm^3
Gravity: 0.905 × Earth's gravity
Rotation: 17.25 hours (retrograde)
Axial Tilt: 97.86°
Sidereal Period: 84.01 years
Synodic Period: 369.66 days
Satellites: 15

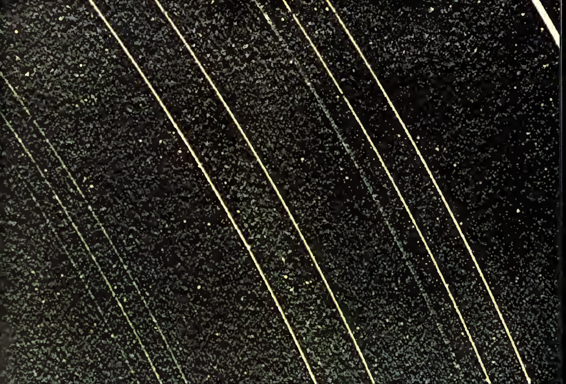
Uranus
Voyager 2 *images*

Another gas giant, Uranus is four times larger than Earth but so distant that it is only barely visible to the naked eye on very dark, clear nights. Its axis is at such a severe tilt (98°) that it lies on its side. Its disk appears bland and almost featureless, as shown in the image at right, which has been color-balanced to approximate what the human eye would see. The dominant blue color is due to absorption of red light by methane in the upper atmosphere, leaving primarily blue light to be scattered back. The brightest portion of the disk, near the center, is the subsolar (noon) point. The image at left has had its color and contrast greatly exaggerated to bring out subtle details. The resulting bull's-eye pattern is centered on Uranus's rotational axis, not on the subsolar point, indicating that winds and weather on Uranus are dominated more by its rotation than by the feeble absorbed sunlight. The pattern is probably caused by a brownish photochemical haze (smog) that is high in the atmosphere near the pole but mostly below the methane at lower latitudes.



Uranus: Rings
Voyager 2 *image*

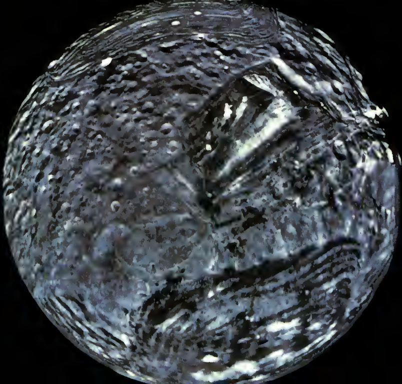
This mosaic of two images shows Uranus's rings, nine of which were known prior to the *Voyager 2* encounter in 1986 from Earth-based telescopic observations of stars being obscured as they passed behind the rings. *Voyager 2* discovered a faint tenth ring, located between the outer two rings. In contrast to the broad, bright rings of Saturn, the rings of Uranus are narrow strings of very dark material. The prominent Epsilon ring, at upper right, is only about 100 km (60 miles) wide. The smallest details that can be discerned in this mosaic are about 20 km (12 miles) across. At this resolution, only the Epsilon and the diffuse Eta (fourth from right) rings reveal any structure at all. The others are too narrow to be resolved. Other data from *Voyager* indicate that the unresolved rings are from 2 to 10 km (1–6 miles) wide. The mottled appearance of the background behind the rings is an artifact of the imaging process. Since the ring material reflects only about 1 percent of the light that strikes it, long exposure times were needed to show the ring material at all.



Miranda Data
Distance from Uranus: 129,900 km (80,700 miles)
Diameter: 480 km (300 miles)
Orbital Period: 1.41 days

Miranda
Voyager 2 *image*

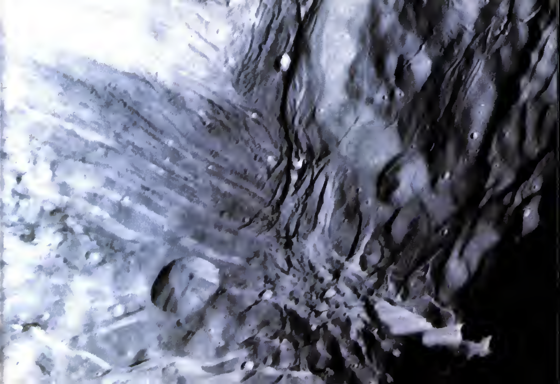
Miranda, the smallest of Uranus's five major satellites (480 km/300 miles in diameter), has the most fascinating geology. Its heavily cratered surface is overlaid with three "coronas" of resurfaced material and numerous cliffs and canyons. Even the craters are unusual: Most of them appear subdued, and the few sharp, fresh ones have a layer of lighter material around their rims. This material is also seen at the tops of the large cliffs, indicating that it may be a global layer. The most prominent bright feature is the "7" in the middle of the rectangular corona just above the moon's center. The lighter corona, at the very top, consists of bands of parallel ridges and troughs. The largest, mottled corona (bottom), displaying concentric bands of alternating brightness, is surrounded by cliffs and small radial canyons. The coronal surfaces appear to have been formed by viscous icy lavas that erupted from fissures into pre-existing features: the "7" corona partly filling a section of the canyon network, the ridged corona overflowing a canyon, and the mottled corona pouring into a large depression, possibly an impact crater.



Miranda: Ice Cliffs

Voyager 2 *image*

The most prominent cliff on Miranda is shown at lower right in this *Voyager 2* image, marching into the darkness of the northern hemisphere. This fresh cliff is actually a long (14–19 km/9–12 miles) slope angled about 40° to the local vertical, with a crest 10 to 15 km (6–9 miles) above the canyon floor. The bright layer seen in other fresh slopes and craters on Miranda is visible at the top of this slope. Streaks down the slope suggest that the face is composed not of solid material but of grains of water ice that at Miranda's temperature (−213°C/−350°F) would have the consistency of gravel. Old crater plains extend from the top of the slope, and the foot of the slope partly covers a highly fractured canyon floor. A set of intersecting subdued slopes can be seen in the upper left portion of this image. Though not as obvious as the fresh slope, these older slopes are similar in size and length. Indeed, the prominent fresh slope is only one section of a global set of large cliffs and canyons.



Ariel Data
Distance from Uranus: 190,900 km (118,625 miles)
Diameter: 1,160 km (720 miles)
Orbital Period: 2.52 days

Ariel
Voyager 2 *image*

Ariel, another of Uranus's satellites, is more than twice as large as Miranda. Its surface has experienced significant internal geologic activity, apparently triggered by excess tidal heating. The oldest parts of the surface are large polygonal blocks or plates, marked with numerous craters. Many of the largest craters are so worn down they are almost invisible. The blocks appear to have simply flowed apart from one another. Some of the smaller blocks, such as the triangular-shaped piece near the large, bright crater below center, are actually tilted several degrees from the surface's horizontal plane. The overall pattern suggests a movement similar to plate tectonics on Earth. The floors of the smaller canyons between the blocks, like the long narrow ones at the top of the image, are simply down-dropped sections of the older surface. The floors of the larger canyons, however, are covered with bulging, smooth deposits left by massive flows of viscous, icy lavas, probably composed of water ice mixed with ammonia and carbon compounds. The flows are 1 to 2 km (½–1¼ miles) thick.

Umbriel Data
Distance from Uranus: 266,000 km (165,300 miles)
Diameter: 1,190 km (740 miles)
Orbital Period: 4.14 days

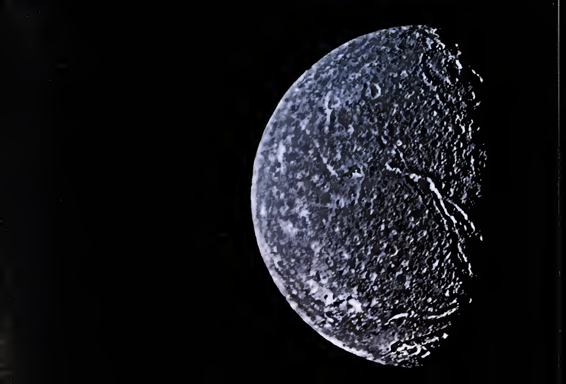
Umbriel
Voyager 2 *image*

Uranus's moon Umbriel is nearly a twin of Ariel in terms of size and density, but their surfaces could hardly present a greater contrast. Umbriel's surface is heavily cratered and very dark, with an average reflectivity of only about 20 percent. The only obvious evidence of internal activity is the bright annulus of material at the top of the image, with inside and outside diameters of about 20 and 80 km (12 and 50 miles), respectively, which is probably icy volcanic material that erupted onto the floor of a large impact crater. Similar bright material appears on the central peak of the fresh crater nearby on the terminator (the line dividing the sunlit part from the nighttime part). However, numerous cliffs and canyons run diagonally across the bottom of the disk (difficult to see in this low contrast image), indicating that fairly significant internal heating and expansion has occurred. Umbriel's uniformly dark surface is puzzling. The material may be a relatively recent thin coating, or it may be the unaltered primitive material from which the satellite formed.

Titania Data
Distance from Uranus: 436,300 km (271,100 miles)
Diameter: 1,610 km (1,000 miles)
Orbital Period: 8.7 days

Titania
Voyager 2 *image*

Titania, with a diameter of 1,610 km (1,000 miles), is the largest of the Uranian satellites and exceeds Saturn's Rhea and Iapetus in size. Its surface is peppered with craters of all sizes and crisscrossed by a global network of giant cliffs, 5 to 6 km (3–4 miles) high, and immense canyons, thousands of kilometers long and 50 to 100 km (30–60 miles) wide. The canyons cut through most craters on the surface, evidence that they occurred later. Aside from the canyons, Titania's surface appears to be so heavily cratered that it might be the original, primitive surface. However, the crater density on Titania is only about half that on its neighbors Umbriel and Oberon and about one-fourth that on the cratered portion of Miranda. Since all of the Uranian satellites would have encountered the same population of objects and debris that made the craters, the low crater density on Titania offers proof that its original surface has been buried by eruptions of global icy volcanic material, even though there are almost no recognizable volcanic features visible.



Oberon Data
Distance from Uranus: 583,400 km (362,525 miles)
Diameter: 1,550 km (960 miles)
Orbital Period: 13.46 days

Oberon
Voyager 2 *image*

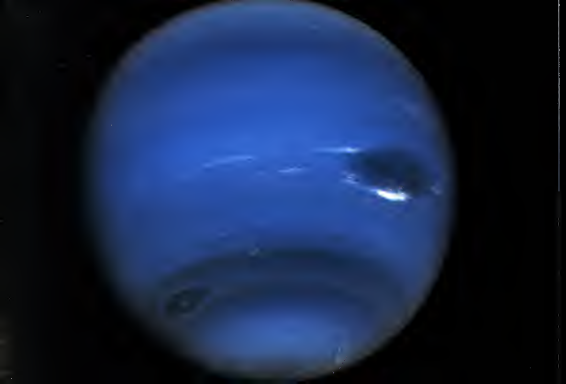
The outermost of Uranus's moons, Oberon shows most of the same types of surface features as Titania. Most prominent are several large impact craters with bright ray systems, formed by material ejected by the blast of the impact. Many craters, including Hamlet, a 200-km (125-mile) diameter crater near the center of the image, also have dark floors that are probably deposits of icy volcanic material. Patches of dark material scattered around the surface are also probably volcanic deposits. Canyons and cliffs are also present on Oberon, but they are less apparent than those on Titania. A fresh canyon cuts across Hamlet, and an older, subdued canyon parallels the terminator (the line between light and dark). The dark materials and the canyons are evidence of significant internal heating and melting. An interesting feature is the large conical mountain on the moon's limb (edge) at lower left. A truly enormous feature by terrestrial standards, it rises at least 20 km (12 miles) above the surface. In form and size it resembles the central peak seen in large impact craters on other icy satellites.

Neptune Data

Distance from Sun: 4,497.07 million km (2,794.48 million miles)
Diameter: 49,500 km (30,750 miles)
Mass: 17.135 × Earth's mass
Density: 1.64 g/cm^3
Gravity: 1.122 × Earth's gravity
Rotation: 16.1 hours
Axial Tilt: 29°
Sidereal Period: 164.79 years
Synodic Period: 367.49 days
Satellites: 8

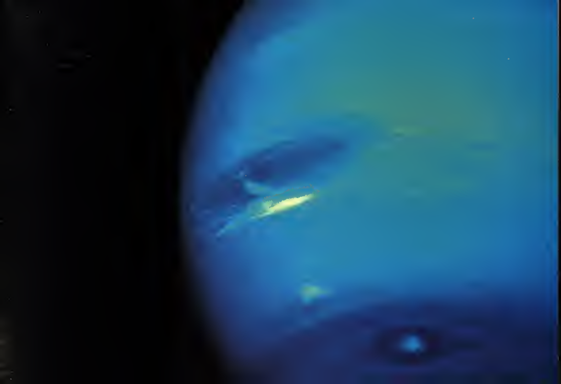
Neptune
Voyager 2 *image*

This image of Neptune shows the atmospheric features of the smallest of the gas giants: latitudinal banding, storm systems, and cloud streaks. The planet's interior rotation (measured from the rotation of the magnetic field) of 16.1 hours drives the atmospheric features around at speeds that range from a few dozen kilometers per hour near the poles to over 1,600 km per hour (1,000 mph) near the equator, making Neptune one of the windiest planets in the solar system. The bands of clouds in Neptune's atmosphere extend all the way to the rotational poles (one pole is visible, near the bottom of the disk). Banded cloud patterns on Jupiter and Saturn, by contrast, are disrupted above about 50° N and S latitudes by upwelling of internal heat from the interiors. The vigorous meteorological activity on Neptune, a great surprise in an atmosphere that absorbs about 900 times less solar energy than Earth does, is still not fully understood. The deep blue color, somewhat exaggerated in this image, is largely due to absorption of longer wavelength (red) light by methane molecules above the visible cloud deck.



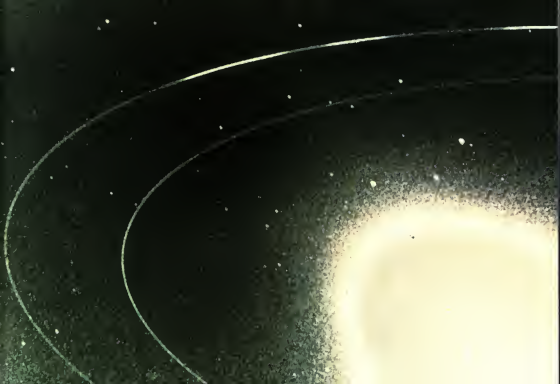
Neptune: Great Dark Spot and Friends
Voyager 2 *image*

This image shows some of Neptune's most prominent atmospheric features in greater detail. The largest is the Great Dark Spot (GDS), which spans 10,000 km (6,200 miles, nearly the diameter of Earth). Like Jupiter's Great Red Spot, it rotates in a counterclockwise direction, an indication that it is an area of high pressure. Unlike the Great Red Spot, the GDS is not the highest feature in the atmosphere. The white streaks of cloud around it are 50 to 100 km (30–60 miles) higher in altitude. The brightest features in Neptune's atmosphere, these cloud clusters change patterns constantly. A smaller dark spot with a core of bright clouds appears near the bottom of the image. Between the two dark spots is a triangle of bright cloud nicknamed the "Scooter" because of its rapid motion. By comparing this image with the preceding global view of Neptune, taken about four days or six Neptune rotations earlier, it is easy to see that these three features circumnavigate Neptune at different rates: all three are in different positions relative to one another.



Neptune: Rings
Voyager 2 *image*

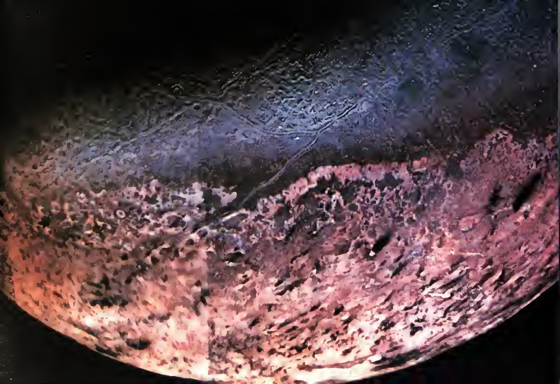
This wide-angle *Voyager 2* image displays the outer two of Neptune's four rings; these lie about 53,000 km and 63,000 km (33,000 and 39,000 miles) from the planet. The thin, sunlit crescent of Neptune is visible in the overexposed oval at lower right. This image was taken after *Voyager*'s closest approach to the planet, looking back toward the Sun, so the rings are seen by light that is preferentially scattered forward along the original direction of travel. The rings are much brighter in this image than in images taken before the encounter, in which the rings are seen by reflected (back-scattered) light. Astronomers learned that the particles in these rings, mostly dust-size, display a tendency to cluster together. Particles in the rings of the other giant planets are generally larger (pebble-size and up) and are much more uniformly distributed. The clusters are thought to be maintained by tiny moonlets too small to be detected directly. *Voyager 2* did detect six small inner satellites, bringing the number of Neptune's known moons up to eight.



Triton Data
Distance from Neptune: 354,000 km (220,000 miles)
Diameter: 2,705 km (1,680 miles)
Orbital Period: 5.88 days (retrograde)

Triton
Voyager 2 *image*

Images of Neptune's large moon Triton returned by *Voyager 2* are among the most incredible of its 12-year mission. This mosaic shows a portion of Triton viewed at high resolution and provides a good overview of the major geomorphic provinces. The rugged terrain with numerous depressions and subdued ridges at upper left is called "cantaloupe" terrain. In the upper right and center is a younger icy volcanic province with vast tracts of smooth and knobby terrain. These deposits appear to be materials blasted in both liquid and particle flows from the depressions, which are thought to be volcanoes of various types. Giant ridges crisscross the entire image. Solid nitrogen covers the lower portion of the mosaic, which encompasses nearly all of the southern hemisphere, covering the underlying terrain like a blanket of snow. The bright smooth areas are blanketed volcanic plains, and the bright rugged areas are blanketed cantaloupe terrain. Triton has very few impact craters, indicating a young surface, perhaps less than a billion years old.



Triton: Polar Cap and Wind Streaks
Voyager 2 *image*

This image shows a portion of Triton's polar areas in detail. The numerous elongated dark streaks, most of which point in the same direction, are thought to be dust dropped onto the surface from previously active geyser-like plumes. At least two currently active plumes were seen elsewhere on Triton as narrow columns extending 8 km (5 miles) into the stratosphere before fanning out into long streaks like the ones on the ground. Triton's atmosphere is 100,000 times thinner than Earth's, yet the common orientation of the streaks on the ground indicates that it is still thick enough to provide winds sufficient to blow the dust particles. The light polar material, probably solid nitrogen, is not uniform in brightness and does not completely obscure the underlying surface features. By taking the vertical dimensions of the surface features and noting which features are buried, astronomers estimated that the "snow" ranges from a few centimeters to a few tens of meters deep.

Pluto Data

Distance from Sun: 5,913.52 million km (3,674.66 million miles)
Diameter: 2,300 km (1,430 miles)
Mass: 0.0022 × Earth's mass
Density: 2.03 g/cm^3
Gravity: 0.06 × Earth's gravity
Rotation: 6.39 days (retrograde)
Axial Tilt: 122.6°
Sidereal Period: 248.54 years
Synodic Period: 366.73 days
Satellites: 1

Pluto

Lowell Observatory discovery plates

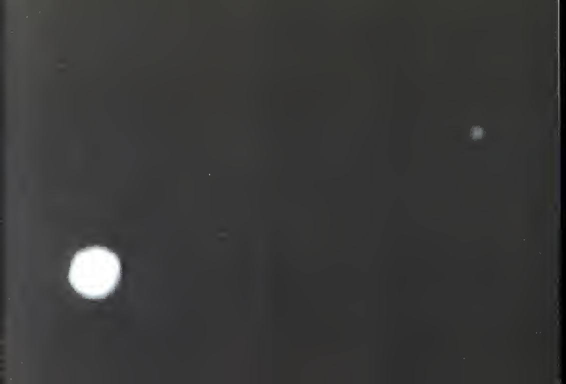
These are two of the three "discovery" plates of Pluto taken in early 1930 at the Lowell Observatory by Clyde W. Tombaugh. These images were part of a painstakingly tedious and deliberate search for a trans-Neptunian planet predicted by the observatory's founder, Percival Lowell. Tombaugh discovered the sought-after planet on February 18, 1930, while using a blink comparator—a kind of microscope that allows the user to alternately examine small areas of each plate in rapid succession. Stars and galaxies appear identical in both images, but moving objects appear to hop back and forth as the operator "blinks" between the two plates. Two images were needed to detect the motion of the faint, starlike image of Pluto; a third was necessary to confirm its motion. As seen in these plates, taken on different dates, the background of stars stays fixed, while solar system objects, such as tiny Pluto (indicated by the arrows), move against it. Although considered the ninth planet, Pluto is actually closer to Earth than Neptune for 20 years of its 248-year orbit.

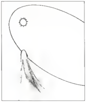
Charon Data
Distance from Pluto: 19,600 km (12,200 miles)
Diameter: 1,190 km (740 miles)
Orbital Period: 6.39 days (retrograde)

Pluto and Charon

Hubble Space Telescope image

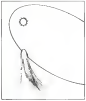
Observing Pluto and deducing its nature have been a challenge to astronomers since its discovery in 1930. With the discovery of its moon, Charon, in 1978, astronomers could finally directly gauge Pluto's gravitational influence on another object and deduce its mass. Pluto is exceeded in size and mass by our Moon, and Charon is half Pluto's size and one-tenth its mass. These determinations have fueled debate over whether Pluto should be classified as a planet. While it orbits the Sun directly, it fits into neither the terrestrial nor jovian planetary classifications, but appears to be most similar to the icy satellites of the outer planets. Pluto may resemble Neptune's moon Triton, which is a bit larger and almost as far out. There are theories that it may be an escaped satellite of Neptune, or that it may be a very large comet. It has been a great challenge to resolve Pluto and Charon separately in photographs. This 1994 Hubble Space Telescope image is the first to resolve their individual disks and the most detailed yet of this far-off pair.





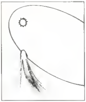
Comet West
Earth-based photograph

The intriguing beauty of comets is brought out in this 1976 photograph of Comet West, with its extended dust tail. The main tail of a comet is composed of dust and always points away from the Sun, regardless of the direction in which the comet may be moving. This is caused by solar wind and radiation pressure pushing the dust outward. Comets also have a less apparent appendage called the ion (plasma) tail. Ion tails always point in a nearly straight line away from the Sun, while dust tails are more curved, with the degree of curvature depending on the size of the dust particles and the orbital speed of the comet. Dust tails are made visible by the light they reflect; ion tails shine by fluorescence. Only comets that come close to the Sun (within the orbit of Jupiter) develop significant tails. As a comet approaches the Sun its tail streams behind it, but when it recedes from the Sun its tail is in front, pushed ahead by solar wind. Some comet tails are 50 to 80 million km (30–50 million miles) long.



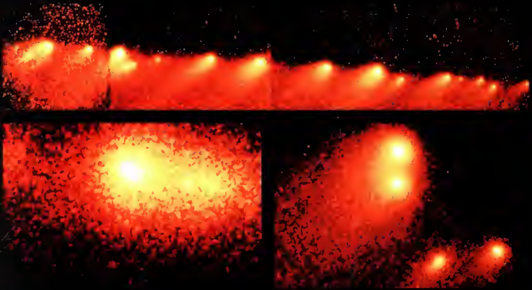
Halley's Comet: Nucleus
Giotto *image*

Halley's comet is probably best known for the regularity with which it passes close to Earth, appearing in our skies every 75 years. The European Space Agency's *Giotto* spacecraft flew by Comet Halley in March 1986, giving us our first close-up view of a comet nucleus. Halley's nucleus is elongated and rather peanut-shaped, measuring about 8 by 15 km (5 by 9 miles). The icy nucleus is dust-coated and dark, with an albedo (reflectivity) of only about 4 percent—about as reflective as dark asphalt. Sunlight heats the comet surface, causing ice and frozen gases to sublimate, or change their physical state directly from solid to gas. Astronomers discovered that the sublimation is quite localized; bright jets of material spew into space from only about 10 percent of the surface at any given time. The remaining 90 percent is relatively inactive "duracrust." Near the pointed edge of Halley's nucleus hints of mountains and craters can be seen. It is not known whether the craters are from impacts or eruptions. Halley's comet will make its next appearance in 2061. A number of comets appear in our skies every year, most of them too dim to be seen by the naked eye.



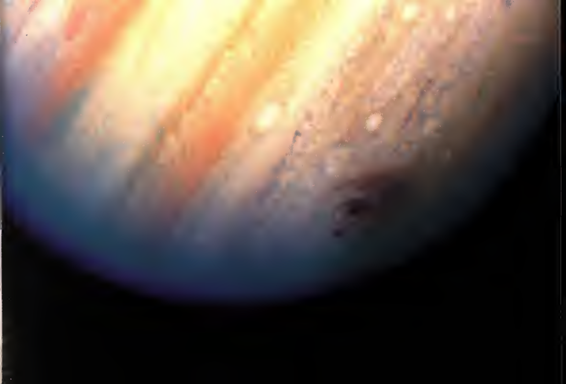
Comet Shoemaker-Levy 9
Hubble Space Telescope images

Comet Shoemaker-Levy 9 (SL-9) was named for its discoverers, Carolyn and Eugene Shoemaker and David Levy, history's most prolific comet hunters. They saw not one but 22 individual fragments creating a string of pearls effect, each pearl with the accompanying hazy glow inherent in comets. Although it was not very bright, its elongated train was unprecedented. The comet's location put it on a path to Jupiter. The discoverers deduced that SL-9 had been disrupted by Jupiter's tidal forces during a close pass in 1992. As astronomers all over the world waited, the comet fragments impacted Jupiter over a six-day stretch in July 1994, the most spectacular celestial train wreck in human history. Each of the impacts imparted more energy into Jupiter's atmosphere than the combined nuclear arsenals of all the nations on Earth. The mean size of the fragments is still being debated, but was probably about 200 to 500 meters (650–1,600 feet) in diameter, with individual fragments as large as 1 to 3 km (½–2 miles) in extent.



Comet Shoemaker-Levy 9: Jupiter Impact Sites
Hubble Space Telescope image

NASA's Hubble Space Telescope captured this image of Jupiter and two of the impact sites produced by its collision with Comet Shoemaker-Levy 9. All 22 fragments of the comet hit Jupiter at about 44° S latitude on the side facing away from Earth. The results of these cataclysmic events could not be seen from Earth until about 20 minutes after each impact, when the planet's rapid rotation brought the scars into view. The two black spots visible in this image were produced by fragment D and, 20 hours later, fragment G. This second one, the larger of the two, turned out to be one of the most spectacular impact features of all. It hit the planet less than two hours before this image was taken. Two rings were produced by shock waves and by hot material blasted upward by the impact, which fell ballistically onto Jupiter's cloud tops. The outer ring's diameter, about 12,000 km (7,500 miles), is slightly larger than Earth's. The results of data recorded during the impact will be studied for years and will most likely impart valuable information about Jupiter's mysterious interior.



Observing the Planets

Because the bodies in our solar system are so much closer to us than any other celestial objects, we can see their movements across the sky and make out many of their details. With binoculars or a small telescope we can see many of the wonders of our solar system: the crescent phase of Venus, the red color of Mars, the Galilean satellites of Jupiter, and the rings of Saturn. The continual movement and changing of positions, as Earth passes the slower-moving outer planets and the faster-moving inner planets pass Earth, make observing our solar system an ever-varying and challenging exercise. We gauge the movements of objects in the sky in relation to the Sun (as discussed in the Introduction) or in relation to the stationary background of stars, especially the zodiacal constellations.

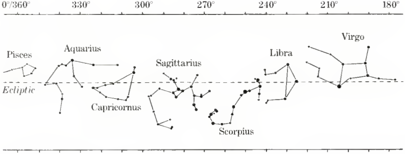
The Ecliptic and the Zodiac
The ecliptic is the path, or the plane, of Earth's orbit projected onto the celestial sphere. (From Earth we see and interpret the ecliptic not as our own orbit, but as the Sun's path around the sky.) Because the orbits of the planets (with the exception of Pluto) are all more or less on the same plane as the orbit of Earth, they also appear to follow the path of the ecliptic, give or take a few degrees, across the sky.

The ecliptic is the centerline of the band of sky known as the zodiac, which extends about 8° north and south of it. The zodiac is divided into 12 segments, each about 30° wide and marked by a constellation. As the planets also move roughly along the ecliptic, they can be found (when they are visible) among the constellations of the zodiac.

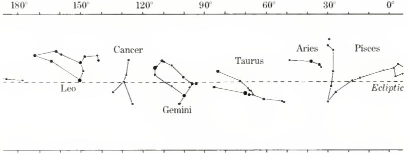
Planetary Longitudes Table
The zodiac chart and the Planetary Longitudes table on the following pages will help you locate planets in the sky. Find the longitude of the planet you wish to observe in the Planetary Longitudes table. (Only those planets visible to the naked eye are listed.) Flip to the zodiac chart and use that longitude (found at the top of the chart) to see in which constellation the planet can be found. If the constellation is visible in your sky that night, you can then find the planet. By observing the planets on successive nights you can track their movements against the stars.

Planet Positions Table
The Planet Positions table gives the dates of the maximum elongations of Mercury and Venus and the oppositions of Mars, Jupiter, Saturn, and Uranus. (Elongation and opposition are explained in the introductory essay "Planetary Motion.") These will help you plan your planetary observing expeditions around the times when the planets are at their largest and brightest.

The Zodiac



0°/360°
330°
300°
270°
240°
210°
180°
Pisces
Aquarius
Sagittarius
Libra
Virgo
Ecliptic
Capricornus
Scorpius



180°
150°
120°
90°
60°
30°
0°
Cancer
Taurus
Aries
Pisces
Leo
Gemini
Ecliptic

Planetary Longitudes: 1995–2000

1995

Date		Mercury	Venus	Mars	Jupiter	Saturn
Jan	1	290	234	153	245	338
	15	312	248	152	247	339
Feb	1	318	266	147	250	341
	15	306	282	142	252	343
Mar	1	313	298	137	254	344
	15	330	314	134	255	346
Apr	1	358	335	133	255	348
	15	25	351	136	255	350
May	1	57	11	140	254	351
	15	75	28	145	253	353
Jun	1	76	48	153	251	354
	15	70	65	160	249	354
Jul	1	77	85	168	247	355
	15	98	102	176	246	355
Aug	1	133	123	186	246	354
	15	159	140	195	246	354
Sep	1	184	161	206	247	352
	15	198	178	215	248	351
Oct	1	196	198	226	250	350
	15	185	216	236	253	349
Nov	1	205	237	248	256	348
	15	227	254	258	259	348
Dec	1	253	274	270	262	348
	15	274	291	281	266	348

1996

Date		Mercury	Venus	Mars	Jupiter	Saturn
Jan	1	299	313	294	269	349
	15	303	330	305	273	350
Feb	1	289	350	319	276	352
	15	300	7	330	279	354
Mar	1	320	24	341	282	355
	15	343	40	352	284	357
Apr	1	15	57	6	287	359
	15	43	70	17	287	1
May	1	58	82	29	288	3
	15	55	88	39	287	4
Jun	1	50	86	52	287	6
	15	61	77	62	285	6
Jul	1	87	72	73	283	7
	15	117	75	83	281	7
Aug	1	149	85	94	280	7
	15	169	97	103	278	7
Sep	1	183	113	114	278	6
	15	178	128	123	278	5
Oct	1	171	146	133	279	4
	15	189	163	141	280	3
Nov	1	218	183	151	283	2
	15	240	200	158	285	1
Dec	1	265	220	166	288	1
	15	284	237	173	291	1

1997

Date		Mercury	Venus	Mars	Jupiter	Saturn
Jan	1	283	258	179	295	1
	15	273	276	183	298	2
Feb	1	289	297	186	302	4
	15	309	315	185	306	5
Mar	1	331	332	183	309	7
	15	358	350	178	312	8
Apr	1	29	11	171	315	10
	15	40	28	168	317	12
May	1	32	48	167	320	14
	15	31	65	168	321	16
Jun	1	47	86	173	322	17
	15	71	103	178	322	18
Jul	1	105	123	185	321	20
	15	132	140	193	320	20
Aug	1	156	160	202	318	20
	15	166	177	210	316	20
Sep	1	158	197	221	314	20
	15	155	213	230	313	19
Oct	1	178	232	241	312	18
	15	202	247	251	312	17
Nov	1	230	266	264	313	15
	15	251	279	274	314	14
Dec	1	270	293	287	317	14
	15	269	301	297	319	14

1998

Date		Mercury	Venus	Mars	Jupiter	Saturn
Jan	1	258	303	311	322	14
	15	273	297	322	325	14
Feb	1	297	289	335	329	15
	15	320	290	346	333	17
Mar	1	346	297	357	336	18
	15	11	308	8	339	20
Apr	1	20	325	21	343	22
	15	11	339	31	346	24
May	1	14	357	43	350	26
	15	30	13	53	352	27
Jun	1	59	32	66	355	29
	15	90	49	75	356	31
Jul	1	120	68	86	358	32
	15	139	84	96	358	33
Aug	1	148	105	107	358	33
	15	140	122	116	357	34
Sep	1	140	143	127	355	33
	15	162	160	136	353	33
Oct	1	192	180	146	351	32
	15	215	198	155	350	31
Nov	1	239	219	165	348	30
	15	255	236	173	348	28
Dec	1	250	256	182	349	27
	15	242	274	190	350	27

1999

Date		Mercury	Venus	Mars	Jupiter	Saturn
Jan	1	261	295	198	349	27
	15	282	313	205	354	27
Feb	1	309	334	212	357	28
	15	334	352	217	0	29
Mar	1	358	9	220	4	30
	15	3	26	222	7	31
Apr	1	351	46	221	11	33
	15	357	63	218	14	35
May	1	17	81	212	18	37
	15	41	97	207	21	39
Jun	1	78	115	205	25	41
	15	104	129	205	28	43
Jul	1	124	142	209	30	44
	15	129	151	214	32	45
Aug	1	120	155	221	34	46
	15	123	150	229	35	47
Sep	1	151	141	239	35	47
	15	177	139	248	34	47
Oct	1	204	145	259	33	46
	15	224	156	269	31	45
Nov	1	241	172	281	29	44
	15	234	186	291	27	43
Dec	1	228	204	304	26	42
	15	246	221	314	25	41

2000

Date		Mercury	Venus	Mars	Jupiter	Saturn
Jan	1	271	241	328	25	40
	15	293	112	338	26	40
Feb	1	323	279	352	28	41
	15	344	296	2	30	41
Mar	1	342	315	14	33	42
	15	333	332	24	35	44
Apr	1	344	353	37	39	46
	15	3	10	47	42	47
May	1	32	30	58	46	49
	15	62	47	68	50	51
Jun	1	93	68	80	54	53
	15	107	85	89	57	55
Jul	1	108	105	100	60	57
	15	101	122	109	63	58
Aug	1	110	143	120	66	59
	15	135	160	129	68	60
Sep	1	168	181	140	70	61
	15	191	198	149	71	61
Oct	1	213	218	159	71	61
	15	225	235	168	71	60
Nov	1	215	255	178	70	59
	15	214	272	187	68	58
Dec	1	236	291	196	66	57
	15	257	308	205	64	56

Planet Positions: Inferior Planets

Mercury	Date	Elongation
	5/12/1995	Eastern
	6/29/1995	Western
	9/08/1995	Eastern
	10/20/1995	Western
	1/02/1996	Eastern
	2/11/1996	Western
	4/23/1996	Eastern
	6/10/1996	Western
	8/21/1996	Eastern
	10/03/1996	Western
	12/15/1996	Eastern
	1/24/1997	Western
	4/05/1997	Eastern
	5/23/1997	Western
	8/03/1997	Eastern
	9/16/1997	Western
	11/28/1997	Eastern
	1/06/1998	Western
	3/19/1998	Eastern
	5/04/1998	Western
	7/17/1998	Eastern
	8/31/1998	Western
	11/11/1998	Eastern
	12/20/1998	Western
	3/03/1999	Eastern
	4/16/1999	Western
	6/28/1999	Eastern
	8/14/1999	Western

Mercury	Date	Elongation
	10/24/1999	Eastern
	12/03/1999	Western
	2/14/2000	Eastern
	3/28/2000	Western
	6/09/2000	Eastern
	7/27/2000	Western
	10/06/2000	Eastern
	11/15/2000	Western
	1/28/2001	Eastern
	3/11/2001	Western
	5/22/2001	Eastern
	7/10/2001	Western
	9/18/2001	Eastern
	10/29/2001	Western
	1/12/2002	Eastern
	2/21/2002	Western
	5/04/2002	Eastern
	6/21/2002	Western
	9/01/2002	Eastern
	10/13/2002	Western
	12/26/2002	Eastern
	2/04/2003	Western
	4/16/2003	Eastern
	6/03/2003	Western
	8/14/2003	Eastern
	9/26/2003	Western
	12/09/2003	Eastern
	1/17/2004	Western

Mercury	Date	Elongation
	3/29/2004	Eastern
	5/14/2004	Western
	7/26/2004	Eastern
	9/09/2004	Western
	11/21/2004	Eastern
	12/30/2004	Western
	3/12/2005	Eastern
	4/26/2005	Western
	7/09/2005	Eastern
	8/24/2005	Western
	11/03/2005	Eastern
	12/12/2005	Western

Venus	Date	Elongation
	1/13/1995	Western
	3/31/1996	Eastern
	8/20/1996	Western
	11/06/1997	Eastern
	3/28/1998	Western
	6/11/1999	Eastern
	10/30/1999	Western
	1/17/2001	Eastern
	6/07/2001	Western
	8/22/2002	Eastern
	1/11/2003	Western
	3/29/2004	Eastern
	8/18/2004	Western
	11/03/2005	Eastern

Planet Positions: Superior Planets

Planet	Opposition
Mars	2/12/1995
	3/17/1997
	4/24/1999
	6/13/2001
	8/28/2003
	11/07/2005
Jupiter	6/01/1995
	7/04/1996
	8/09/1997
	9/16/1998
	10/23/1999
	11/28/2000
	1/01/2002
	2/02/2003
	3/04/2004
	4/03/2005

Planet	Opposition
Saturn	9/14/1995
	9/26/1996
	10/10/1997
	10/23/1998
	11/06/1999
	11/19/2000
	12/03/2001
	12/17/2002
	12/31/2003
	1/13/2005
Uranus	7/21/1995
	7/25/1996
	7/29/1997
	8/03/1998
	8/07/1999
	8/11/2000
	8/15/2001
	8/20/2002
	8/24/2003
	8/27/2004
	9/01/2005

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